Workshop on information optics

July 1-5, 2019 Stockholm, Sweden

Springer Nature
IEEE Women in Engineering
KTH
European Optical Society
RISE
Stockholm Municipality
IEEE Photonics

Welcome!

After 20 years of running the Workshop on Information Optics (WIO) in different countries, it is our pleasure to welcome you to the WIO 2019 taking place in Sweden at KTH Royal Institute of Technology in Stockholm (Kista campus).

The workshop will address the latest advances in information optics and photonics, imaging sciences and engineering, optics/photonics communication, display technologies and 3D displays, 3D image sensing, image-based information security, image recognition, biophotonics, and novel image sensors. It will be a forum for scientific interaction and collaboration between well-known scientists in the field and educational outreach to students.

The workshop has started with the Euro-American Workshop on Optical Pattern Recognition in La Rochelle, 1994.

Program chairs

Prof. Sergei Popov,
KTH, Sweden

Prof. Bahram Javidi,
University of Connecticut, USA

It is a small workshop (typically limited by 50 talks, single session), with invited participants broadly from the area of information optics and photonics.
Always there has been an emphasis on allowing time for interaction, collaboration, and networking in a friendly atmosphere. Participants stay together for lunch and social outing.

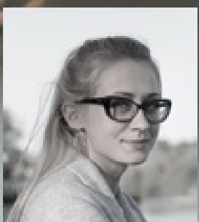
This year we have prepared special surprises for WIO participants - reception at the City Hall of Stockholm where Nobel banquettes take place and conference dinner onboard of an authentic ship M/S Gustavsberg VII where participants can enjoy water cruise and traditional Swedish food.

The workshop will hold in Kista campus of KTH situated in the northern part of Stockholm.
This location can be reached by 20 min journey by sub-way from the center of Stockholm.

Scientific topics

3D image sensing, processing, and display: digital holography, integral imaging
Biophotonics and biomedical imaging
Image-based security and optical security systems
Polarimetric and multi spectral imaging
Materials and devices for information optics
Optical communication
Nano-technologies for imaging systems
Quantum optics for communication and imaging
Integrated sensing and imaging, compressive sensing
Diffractive optics
Inverse problems in optics
Spatial light modulators and applications in information optics
New radiation sources for information optics (UV - THz)

Organizing committee



Dr. Elena Vasileva,
KTH, Sweden

Dr. Qin Wang,
RISE, Sweden

Dr. Oskars Ozolins,
KTH, RISE, Sweden

Dr. Anne-Sophie Poulin-Girard,
Université Laval, Canada

TABLE OF CONTENTS

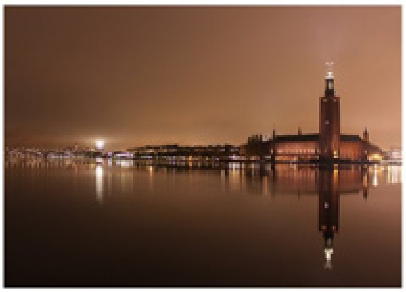
SOCIAL EVENTS

Welcome reception. June 30th, at 19:00

Memory hotel, close to the conference venue.

Conference dinner. July 2nd, 19:00 - 23:00

Unforgetable evening onboard of an authentic ship M/S Gustavsberg VII.
Dinner and water jorney around Stockholm.
Bus transportation will be arranged to and from the event.



Reception in the City Hall of Stockholm. July 4th, 19:00- 21:00

The reception is hosted by the City of Stockholm (Stadshuset).
With the brief story, buffé, and guided tour around the building.
Bus transportation will be arranged to and from the event.

SUPPORTED BY

IEEE photonics SOCIETY · EOS European Optical Society · IEEE Women in Engineering WIE · KTH VETENSKAP OCH KONST · RI. SE · Stockholms stad · SPRINGER NATURE Technology & Publishing Solutions

GENEARL INFORMATION

VENUE

1 - 5 July 2019

Sal C, 2nd floor, KTH Royal Institute of Technology, Electrum building, Isafjordsgatan 22, Kista, Stockholm, Sweden.

VENUE by public trasnport

To get to Kista campus from central station (T-centralen) by subway you need to take a blue line towards Akalla and get off at the metro stop called Kista. The journey takes approximately 20 min.

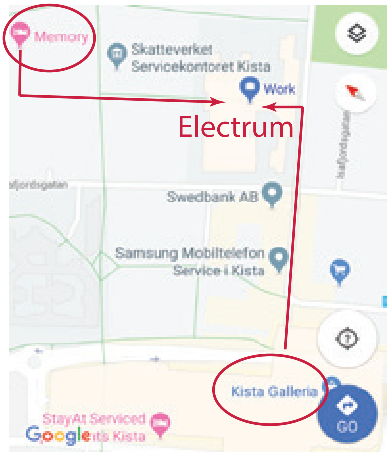
You can buy SL-card at any station or in Pressbyrån shop.
There are different options available:

- Single ticket (45-65 sek). The ticket is valid for 75 minutes
- 24 hours- card (130 sek)
- 72 hours-card (260 sek)
- 7 days-card (335 sek)

For more info

Single ticket Other options

VENUE by walking



Coming with subway:

Take the subway exit towards Kista Galleria (shopping mall).
When enter to the Galleria turn left and follow all the way through it.
Once you leave the mall, follow the street straight ahead and walk over a small bridge. The first building on the left is Electrum.

Coming from the Memory hotel:

Once you leave the hotel, walk straight and cross a car parking, then turn left and follow the path.

EMERGENCY

In case of emergency issues, please, call 112.
In case of local problems or issues, please, contact the organisers.

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Elena Vasileva +46737652022
Annika Wendell +4687904001

CURRENCY

The currency is Swedish crona (SEK).
You can pay with credit card everywhere, and most of the places are cash-free.

WI-FI

Eduroam (education roaming) which is an international roaming service for users in research, higher education and further education will be available during the conference. We offer a local temporary network for you who do not have access to Eduroam. Please contact us during the workshop if that would be the case.

Island Djurgården

Vasa museum

The Vasa Museum is a maritime museum. It displays the only almost fully intact 17th-century ship that has ever been salvaged.
The only authentic battle ship in the world from XVII century.

For more info

Skansen

Skansen is the first open-air museum and zoo in Sweden.
It was opened to show the way of life in the different parts of Sweden before the industrial era.

For more info

Gamla stan (The Old city)

Gamla Stan - heart of Stockholm.
Nobel museum
The Royal Palace – Kungliga Slottet

For more info

Island Lovön

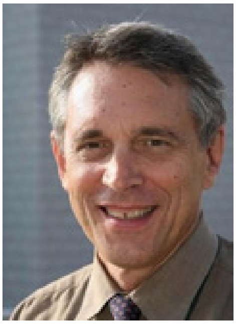
Drottningholm Palace

Sweden's best-preserved royal palace from XVII century, the permanent residence of the royal family and one of Stockholm's three World Heritage Site

For more info

KEYNOTE SPEAKERS

KEYNOTE SPEAKERS

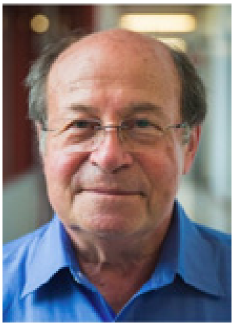


Prof. D. Psaltis, EPFL, Switzerland

Demetri Psaltis, PhD, DSc, is a Professor in Bioengineering and Director of the Optics Laboratory of the EPFL. He is one of the founders of the term and the field of optofluidics, and is also well known for his past work in holography, especially with regards to optical computing, holographic data storage, and neural networks. He is an author of over 350 publications, contributed more than 20 book chapters, invented more than 50 patents, and currently has a h-index of 80.He is a Fellow of OSA, IEEE, and SPIE, and a recipient of Emmett N. Leith Medal, SPIE Dennis Gabor Award, Humboldt Prize for Senior U.S. Scientists, NASA Space Act Award, International Commission for Optics (ICO) Prize for contributions in Optical Information Processing.

Associate Prof. A. Mahalanobis, UCF, USA

Abhijit Mahalanobis, PhD, DSc, joined UCF from Lockheed Martin, where he was a Senior Fellow of the Lockheed Martin Corporation. His primary research areas are in Systems for Information processing, Computational Sensing and Imaging, and Video/Image processing for information exploitation and ATR. He also serves on the organizing committees for the SPIE conferences, and OSA's annual and topical meetings. He has over 170 journal and conference publications in this area. He also holds 4 patents, co-authored a book on pattern recognition, contributed several book chapters, and edited special issues of several journals. He is an IEEE, OSA and SPIE Fellow, and a recipient of Hughes Business unit Patent Award, Innovator of the Year award (1999), Distinguished Member of Technical Staff, the Lockheed Martin Technical Excellence award, the Author of the Year award (2001), the Inventor of the Year (2005), Lockheed Martin NOVA award, the Corporation's highest honor. He was also elected to the Raytheon Honors program and recognized as the 2006 Scientist of the Year by Science Spectrum Magazine, a publication of the Career Communication Group, Inc..



Prof. Y. Fainman, UCSD, USA

Yeshaiahu Fainman, PhD, DSc, is a Cymer Professor of Advanced Optical Technologies in Electrical and Computer Engineering at the University of California, San Diego (UCSD). He directs the Ultrafast and Nanoscale Optics (UNO) group in research of nanophotonics for information processing. He and his UNO group helped to exploit near field optical phenomena in nanophotonic technologies for optical information and signal processing applications. His current research interests are in near field optical science and technology compatible with CMOS manufacturing. Current projects include nanoscale resonant optical phenomena for filtering, modulation and emission of light, quantum emitters, multimodal photonic transducers for medical diagnosis, optical processing with femtosecond pulses, and nonlinear optical microscopy for deep brain imaging. He contributed over 280 manuscripts and 450 conference proceedings. He is a Fellow of OSA, IEEE, and SPIE, and a recipient of Miriam and Aharon Gutvirt Prize, Lady Davis Fellowship, Brown Award, Gabor Award, Emmett N. Leith Medal and Joseph Fraunhofer Award/Robert M. Burley Prize.

Prof. N. Zheludev, ORC, Southampton, UK

Nikolay Zheludev, PhD, DSc is Professor of Physics at the University of Southampton (UK). He is deputy director of the Optoelectronics Research Centre at Southampton and co-Director of the Photonics institute at NTU, Singapore. His research interests are in nanophotonics and metamaterials. His personal awards include the Thomas Young Medal for "global leadership and pioneering, seminal work in optical metamaterails and nanophotonics", Senior Professorships of the Engineering and Physical Sciences Research Council (UK) and the Leverhulme Trust and the Royal Society Wolfson Research Fellowship. Professor Zheludev is the Editor-in-Chief of the IOP "Journal of Optics" and advisor to the Nature-Springer Publishing Group.

TECHNICAL PROGRAM

MONDAY, JULY 1

09:00 Registration, morning coffee

09:30 Bahram Javidi, Sergei Popov, Sylvain Gigan
Welcome introduction

09:55 Matthieu Roussey, University of Eastern Finland, Finland
Facilitated integrated photonics

10:15 José Manuel Rodríguez-Ramos, Univesity La Laguna, Wooptics SL, Spain
SEBI camera: a real time FullHD single-lens lightfield camera

10:35 Fernando Mendoza, Centro de Investigaciones en Optica, A.C., Leon, Mexico
Cellular and nano materials research using digital holography with electrons and photons

10:55 Coffee break

11:20 Zeev Zalevski, Bar-Ilan University, Israel
Fibers-based photonic information processing unit

11:40 Hitoshi Tabata, The University of Tokyo, Japan
Near IR plasmonics based on nano-patterned metallic antennas and oxide semiconductors for bio-medical sensing

12:00 Tomohiro Shirai, National Institute of Advanced Industrial Science and Technology AIST, Japan
Interferometry based on classical ghost imaging

12:20 Lunch

14:00 Bahram Javidi, University of Connecticut, USA
Learning in the dark: 3D object recognition in very low illumination conditions using convolutional neural networks and integral imaging

14:20 Giancarlo Pedrini, University of Stuttgart, Germany
Multi-wavelengths digital holography for erosion measurements under extreme environmental conditions inside the ITER Tokamak

14:40 Guilherme Xavier, Linköping University, Sweden
Quantum information with multi-core fibers

15:00 Esteban Vera, Pontifica Universidad Catolica de Valparaiso, Chile
Multiframe superresolution meets compressive imaging

15:20 Coffee break

15:40 Simon Thibault, University Laval, Canada
Using optical short pulse in optical engineering

16:00 Mohamed Bourennane, Stockholm University, Sweden
Secure multi-party quantum communication

16:20 Free time

TUESDAY, JULY 2

09:00 Registration, morning coffee

09:30 Demetri Psaltis, EPFL, Switzerland
Keynote talk "Learning, neural networks and optics"

10:15 Yasuhiro Awatsuji, Kyoto Institute of Technology, Japan
High-speed imaging of dynamic and transparent object by parallel phase-shifting digital holographic microscope

10:35 Cefe Lopez, Instituto de Ciencia de Materiales de Madrid (ICMM), Spain
Order and porosity increase optical materials' versatility

10:55 Coffee break

11:20 Laura Lechuga, Catalan Institute of Nanoscience and Nanotechnology (ICN2), Spain
Advanced nanophotonic point-of-care biosensors for ultrasensitive real-time analysis

11:40 Sergiy Valyukh, Linköping University, Sweden
Near to-/on eye display

12:00 Igor Zouzulenko, Linköping University, Sweden
Optics of conducting polymers

12:20 Lunch

14:00 Oskars Ozolins, RISE Research Institute of Sweden, Sweden
100Gbaud pulse amplitude modulation links for optical interconnects

14:20 Magnus Karlsson, CTH Chalmers University of Technology, Sweden
High spectral efficiency transmission based on frequency combs

14:40 Osamu Matoba, Kobe University, Japan
Holographic 3D stimulation and observation for neuroscience

15:00 Kenneth Järrendahl, Linköping University, Sweden
Optical biomimetics – polarization studies of scarab beetles

15:20 Coffee break

15:40 Technical session
IEEE Photonics Sweden
Springer-Nature publisher (JEOS:RP journal)
European Optical Society

16:20 Free time

19:00-23:00 Conference dinner

NB! A bus to the dinner venue departs at 18:00. Meeting point - conference venue.
A return bus to the conference venue leaves at 23:20.

WEDNESDAY, JULY 3

09:00 Registration, morning coffee

09:30 Abhijit Mahalanobis, University of Central Florida, USA
Keynote talk "Optimizing measurements for task specific compressive sensing"

10:15 Martti Kauranen, Tampere University, Finland
Nonlinear microscopy of nanostructures using cylindrical vector beams

10:35 Hilton Barbosa de Aguiar, Ecole Normale Supérieure/Paris, France
Fast chemical imaging via compressive Raman microscopy

10:55 Coffee break

11:20 Miguel Alonso, Fresnel Institute, France; University of Rochester, USA
Nonparaxial polarization: basic elements and application in fluorescence microscopy

11:40 Sergei Ponomarenko, Dalhousie University, Canada
Diffraction-free beams on incoherent background

12:00 Xiaofeng Peng, Soochow University, China
Twisted Laguerre-Gaussian Schell-model beam and its orbital angular momentum

12:20 Lunch

14:00 Amr Helmy, University of Toronto, Canada
Utilizing quantum correlations in practical, noise resilient imaging modalities

14:20 Ari Friberg, University of Eastern Finland, Finland
Vector wave beating

14:40 Elena Vasileva, KTH Royal Institute of Technology, Sweden
Polarization of light porpagating through transparent wood

15:00 Göery Genty, Tampere University, Finland
Ghost imaging in the temporal domain

15:20 Coffee break

15:40 Adrian Stern, Ben-Gurion University of the Negev, Israel
Phase space models for wave propagation through disordered media

16:00 Stephane Junique, RISE Research Institute of Sweden, Sweden
Asymmetric Free-Space optical link using a modulating retro-reflector

16:20 Maxime Jacquot, Femto-St Optic / UFC, France
The shape of light: how to measure, control and compute complexity

16:40 Free time

THURSDAY, JULY 4

09:00 Registration, morning coffee

09:30 Yeshaiahu Fainman, University of California San Diego, USA
Keynote talk "Integrated nanophotonics: technology and applications"

10:15 Toru Iwane, Nikon Corp., Japan
Light-field optics and aerial imaging

10:35 Andriy Shevchenko, Aalto University, Finland
Aberration-insensitive microscopy using interferometric ghost-like imaging

10:55 Coffee break

11:20 Fredrik Laurell, KTH Royal Institute of Technology, Sweden
Mid-infrared ranging facilitated through intra-cavity up-conversion

11:40 Majid Ebrahim-Zadeh, ICFO-The Institute of Photonic Sciences, Spain
Progress in ultrafast optical parametric oscillators

12:00 Cristian Neipp, University of Alicante, Spain
Holographic waveguides recorded on photopolymer materials

12:20 Lunch

14:00 Sergei Sekatskii, EPFL, Switzerland
Photonic crystal supported surface electromagnetic waves and their use for generation of long propagating surface plasmon - polaritons and ultrasensitive label-free biosensing

14:20 Lech Wosinski, KTH Royal Institute of Technology, Sweden
Hybrid plasmonics for optical interconnects and sensing

14:40 Toralf Scharf, EPFL, Switzerlan
Near field interference of ordered micro-optical elements and their far field intensity patterns

15:00 Yi-Pai Huang, Apple Corp., Taiwan
Title TBD

15:20 Coffee break

15:40 Student session

16:40 Free time

19:00 - 21:00 Reception in the City Hall of Stockholm

NB! A bus to the dinner venue departs at 18:00. Meeting point - conference venue.
A return bus to the conference venue leaves at 21:20.

STUDENT SESSION

THURSDAY, JULY 4

15:40 Maryam Yousefi, EPFL, Switzerland
Contrast of diffraction pattern from sinusoidal phase gratings under Gaussian beam illumination

15:50 Markus Nyman, Aalto University, Finland
Wave retarders and waveguide couplers made of anisotropic metamaterials

16:00 Adil Baitenov, KTH Royal Institute of Technology, Sweden
Diffusion model of light scattering in anisotropic media and extraction of fundamental properties

16:10 Jun Zeng, Sochoow University, China
Partially coherent fractional vortex beam

16:20 Ihar Faniayeu, Göteborg University, Sweden
All-dielectric optical nanoantenna for dynamic beam steering

16:30 Felix Lévesque-Désrosiers, University Laval, Canada
Title TBD

FRIDAY, JULY 5

09:00 Registration, morning coffee

09:30 Nikolay Zheludev, ORC, University of Southampton, UK;
Nanyang Technological University, Singapore
Keynote talk "Metamaterials, anapoles and flying donuts"

10:15 Enrique Tajahuerce, Universitat Jaume I, Spain
Computational imaging with single-pixel detection: application to wavefront sensing and imaging through turbid media

10:35 Alexandr Dmitriev, Göteborg University, Sweden
Magnetic, chemical and electrical steering of optical nanoantennas

10:55 Coffee break

11:20 Lars Thylen, KTH Royal Institute of Technology, Sweden
Integrated nanophotonics for information technologies and sensors: status and some options for the future

11:40 Caroline Amiot, Tampere University, Finland
Ghost imaging in the spectral-domain and its application to broadband spectroscopy and optical coherence tomography

12:00 Shuming Jiao, Shenzhen University, Nanophotonics Research Center, China
Motion estimation and quality enhancement for a single image in dynamic single-pixel imaging

12:20 Lunch

14:00 Tianhua Xu, University of Warwick, UK
Information rates in EDFA and Raman amplified optical communication systems using nonlinearity compensation

14:20 Sergei Popov, KTH Royal Institute of Technology, Sweden
Closing the workshop

MONDAY, JULY 1

Facilitated integrated photonics

Matthieu Roussey,[1] **Ségolène Pélisset,**[1] **Ratish Rao**[1]

[1]University of Eastern Finland, Department of Physics and Mathematics, Joensuu, 80101, Finland

email: matthieu.roussey@uef.fi

The high demand in integrated devices is pushing research and development in this field towards easier and faster fabrication techniques. Despite the recent progress in integrated optics observed in silicon photonics and other glass-based optical component, some platforms still suffers of heavy, expensive, and high-skill demanding techniques. We propose here a simple concept of platform enabling at the same time the total integration, on the same chip, of passive, active, and tunable components made of several different materials, and a relaxed overall fabrication allowing exceptional tolerances.

The platform is based on the concept of strip loading in high refractive index thin films [1,2]. The low effective index contrast of the waveguide structures lead to less demanding constraint in terms of structure geometry and alignment. Integrated towards a horizontal slot waveguide a gigantic property enhancement coming from a high field confinement can be achieved. Together with a detailed example, we will present several devices and future applications.

Multimode interferometer device

As an example, we will present a multimode interferometer device (MMI), which a structure known for its sensitivity to the fabrication. We realized the device by means of atomic layer deposition for the waveguide layers and electron beam lithography for the patterning of the polymer strip-loaded structure. Figure 1 illustrate the field distribution inside a 1x2 MMI (simulated by finite-difference time domain method). One can see the perfect splitting of the modes. Experimental characterizations have shown a very good agreement with the simulations despite some stitching error in the patterning due to the different e-beam exposure dose used for the different part of the structure. Several MMI configurations have been studied.

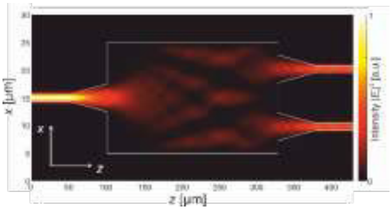


Fig. 1. Field distribution inside the MMI.

In addition to this example of micro-photonics, we will present also several other components, showing how such a versatile platform can enable the fabrication of integrated optical components using mass-production compatible methods like nano-imprinting, for instance.

References

[1] M. Roussey, L. Ahmadi, S. Pélisset, M. Häyrinen, A. Bera, V. Kontturi, J. Laukkanen, I. Vartiainen, S. Honkanen, M. Kuittinen, "Strip-loaded horizontal slot waveguide," *Opt. Lett.* **42**, 211–214, 2017.

[2] S. Pélisset, J. Laukkanen, M. Kuittinen, S. Honkanen, M. Roussey, "Modal properties of a strip-loaded horizontal slot waveguide," *J. Eur. Opt. Soc. – Rapid Publ.*, **13**:37, 2017.

SEBI camera: a real time FullHD single-lens lightfield camera

R. Oliva,[1] S. Ceruso,[1] M. Sicilia,[1] D. Carmona-Ballester,[1] J.M. Trujillo-Sevilla,[1] L.F. Rodríguez-Ramos,[2] O. Gómez-Cárdenes,[1] O. Casanova,[1] J.M. Rodríguez-Ramos[1,3]

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[2]L.F. Sistemas SL, calle La Música, La Laguna, 38208 , Spain

[3]CIBICAN, Campus Ciencias de La Salud, s/n, La Laguna, E-38071, Spain

email: jmramos@wooptix.com

We will present a new real time single lens lightfield camera: SEBI (Sensing the Electromagnetic Behavior by Intensity). The camera is based on focal stack acquisition using a liquid-lens. The computation is based in both platforms of specialized electronic hardware: FPGA and GPU.

After acquiring the lightfield of the scene, several features can be offered also in real time: 3D stereo display, integral 3D display, refocus at will, virtual point of view generation…The GPU implementation can manage FullHD images and displaying them in real time. The FPGA implementation can also manages 4k images and displaying the integral composition in real time.

With SEBI, we aim to establish a new standard in lightfield generation and wavefront phase calculus, applied in real-time for video processing. Thus, we provide an enabling technology with potential in multiple applications, ranging from scientific and industrial metrology to 3D content filming.

A very detailed explanation of the SEBI camera is contained on this link [1].

Fig. 1. This figure shows the internal parts of the SEBI camera: Conventional optical objective, Liquid lens, GPU/FPGA, integral 3d output.

References

[1] https://youtu.be/kvW3GWEurOE

Cellular and nano materials research using Digital Holography with electrons and photons

Fernando Mendoza Santoyo[1]
[1]Centro de Investigaciones en Optica, A.C., Optical Metrology, Leon, Guanajuato, 37150, Mexico
email: fmendoza@cio.mx

Dennis Gabor invented Holography in 1949. His main concern being the aberration correction in the recently created electron microscopes. At the time the lack of coherent electron sources meant that the hologram reconstruction was done using quasi-coherent light sources. As such Holography did not produce enough results to be considered a must use tool, even though a device called a wire-biprism was invented to combine the object and reference beams. The invention of the laser at the end of the 1950's gave a great leap to Holography since this light source was highly coherent, and hence led to the invention of Holographic Interferometry (HI) during the first lustrum of the 1960's. This new discipline in the Optics field has successfully evolved to become a trusted tool in a wide variety of areas. Coherent electron sources were made available by the late 1970's, a fact that also gave an outstanding impulse to electron holography not only due to the coherent field electron guns used in the hologram reconstruction process, but also because of the appearance of electron holographic interferometry (EHI) as a "quasi-non-invasive" measurement tool in electron microscopes. Today nanomaterials and structures belonging to a wide variety of subjects can be characterized in regards to their physical and mechanical parameters using HI with light sources and EHI. This invited presentation will present and discuss the state of the art in HI and EHI applications to study the shape of nanoparticles, cells and bacteria.

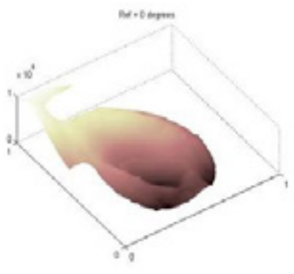

Fig. 1. Bacteria morphology with TEM

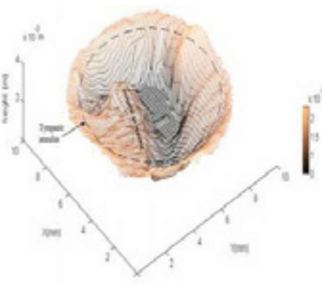

Fig. 2. Tympanic membrane shape

References

[1] E Ortega et. al., Microscopy Research and Technique, **80** (12), pp 1249-1255 (2017).
[2] S Muñoz Solís et. al., *Biomedical Optics Express*, **3** (12), pp. 3203-3210 (2012).

Fiber-based Photonic Information Processing Unit

Nadav Shabairou[1], Eyal Cohen[1,2] and Zeev Zalevsky[1,2]

[1]Faculty of Engineering and the Nanotechnology Institute, Bar-Ilan University, Ramat-Gan, 52900, Israel

[2]CogniFiber Ltd., 11 Haavoda st., Rosh ha Ayin, Israel

The main problem today in the world of processing is the bandwidth of the proposed processors and their power dissipation. In both of those aspects, optics can offer a significant improvement. Specifically, optical neural networks are a good candidate since they allow relatively simple optical realization and yet can provide computational flexibility.

In this presentation we will present a conceptual design for in-fiber optical neural network, capable of realizing processing unit. Neurons and synapses are realized in two ways: first as individual silica cores in a multi-core fiber and then within a multi-mode fiber.

In the first realization optical signals are transferred transversely between cores by means of optical coupling. Pump driven amplification in erbium-doped cores mimics synaptic interactions. Simulations and experimental validation show classification and learning capabilities. Therefore, multi-core fiber-based devices could potentially serve as building blocks for future large-scale small-volume optical artificial neural networks.

In the second type of realization we propose the design of an optical artificial neural network-based imaging system that has the ability to self-study image signals from an incoherent light source in different colors. Our design consists of a multi-mode fiber realizing a stochastic neural network. We show that the signals, transmitted through the multi-mode fiber, can be used for image identification purposes and can also be reconstructed using artificial neural networks with a low number of nodes.

Near IR Plasmonics based on Nano Patterned Metallic Antennas and Oxide Semiconductors for Bio-Medical Sensing

Hitoshi Tabata[1]
[1]The University of Tokyo, Department of Bioengineering, Tokyo, 113-8656, Japan
email: tabata@bioeng.t.u-tokyo.ac.jp

We are studying research field of biophotonics using nano-patterned metallic antennas and oxide plasmonics based on oxide semiconductors.

Surface Plasmons (SPs) have been applied to observe chemical binding of molecules in biochemical fields, which have been realized using noble metals (e.g.; Au and Ag) [1]. In particular, SPRs in the infrared (IR) range have attracted much attention for biosensing applications based on presence of fingerprints of molecular vibrations. However, light confinements onto layer surfaces are weak due to the dispersion relations of noble metals since nanoantenna structures have commonly been used to excite infrared SPRs. In contrast, oxide semiconductors are one of promising materials to control SPR excitations in the IR range by control of free carriers [2], corresponding to dispersion engineering dependent on material-type. This method aims at being excited SPRs efficiently in the infrared range. Recently, we achieved strong light confinements in the infrared range without nanoantenna structures using Ga_2O_3 dielectric-assisted SPR with metallic ZnO: Ga layers, which will be reported from viewpoints of SPR properties and sensing performance in this presentation.

High Special Resolved Cell-extra Cellular Interaction using Local Surface Plasmon [3,4] Single nano-antenna spectroscopy was carried out on realistic dipole nanoantennas with various arm lengths and gap sizes fabricated by electron-beam lithography. A significant difference in resonance wavelength between realistic and ideal nanoantennas was found by comparing their spectral response. Figure 1 shows simultaneous imaging of cancer cell by optical microscope and local surface plasmon using Vis-NIR light. Our results provide important information for the design of dipole nanoantennas clarifying the role of the structural modifications on the resonance spectra, as supported by calculations.

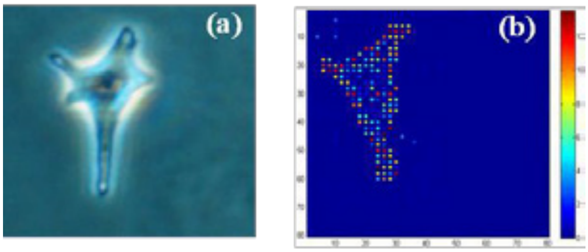

Fig. 1: Cancer cell imaging by (a) optical microscope and (b) LSPR plasmon

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Interferometry based on classical ghost imaging

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Optical imaging of phase objects has been the subject of great importance in connection with modern biomedical research. Interferometric techniques are commonly employed to visualize pure phase objects. In this paper, we propose a new type of phase-measuring interferometry based on ghost imaging with classical incoherent light.

Ghost imaging is an interferometric technique for obtaining an image of an object by measuring the correlation between two beams [1]. However, pure phase objects cannot be seen with a standard ghost imaging setup [2]. Special techniques, such as phase-contrast ghost imaging, are required to visualize them instead [3]. Our proposal in this paper provides a more direct method for phase measurement than those existing techniques.

Figure 1 shows a setup for phase measurement based on classical ghost imaging. The amplitude transmittance of the phase object is characterized by $T(\boldsymbol{\rho}) = \exp[i\phi(\boldsymbol{\rho})]$. This setup is constructed in such a way that a Mach-Zehnder interferometer (MZI) is incorporated into the test arm of the standard ghost imaging setup. This setup may thus be referred to as a ghost MZI. For generality in analysis, we deliberately introduce two quantities Δz and $\Delta\boldsymbol{\rho}$ to unbalance two arm lengths in the MZI and to misalign two beams propagating in these two arms, respectively.

Suppose the ghost imaging condition $z_c = z_a$. In a special case when $\Delta z = \Delta\boldsymbol{p} = 0$, we obtain for the correlation between intensity fluctuations at detectors 1 and 2 the expression

$$G_B(\boldsymbol{\rho}_1) = A\{1 + cos[[\phi(\boldsymbol{\rho})_1]\}, \quad (1)$$

where A is a positive constant. Equation (1) shows that the interference fringe patterns characterizing the object phase can be observed by scanning point-like detector 1 with bucket detector 2 being kept fixed. In other words, phase imaging is possible with the ghost MZI of this kind in the same way as conventional ghost imaging.

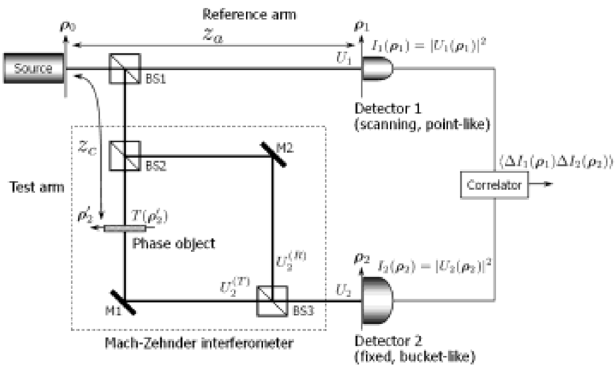

Fig. 1. Setup for a ghost Mach-Zehnder interferometer.

It is also found theoretically that similar interference fringe patterns can be observed, irrespective of the value of $\Delta\boldsymbol{\rho}$, when the two arm lengths in the MZI are not exactly the same (i.e., $\Delta z \neq 0$). This result reveals that *robust* phase imaging with spatially incoherent light is achievable by means of the proposed setup in the sense that requirements for the setup are somewhat relaxed.

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Learning in the dark: 3D object recognition in very low illumination conditions using Convolutional Neural Networks and Integral Imaging

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This invited paper and presentation is an overview of our published work on 3D object recognition in low light levels using commercially available inexpensive image sensors in the visible domain [1-2]. We have proposed and experimentally demonstrated a framework for three-dimensional (3D) object recognition and classification in very low illumination conditions using convolutional neural networks (CNNs). In our proposed approach, 3D images are reconstructed using 3D integral imaging (InIm) [3-8] with conventional visible range image sensors such as low cost compact CMOS sensors. We have shown that capturing and processing the low light scene using 3D InIm results in a 3D reconstructed image with higher signal-to- noise ratio than a single 2D image. This is due to the fact that 3D InIm is optimal in the maximum likelihood sense for noise dominant images such as noise due to the camera read noise. Additional processing is applied after 3D reconstruction has been performed. These include performing denoising on the 3D image. Also, regions of interest are extracted to detect and classify 3D objects in the scene. The extracted regions are further processed by convolutional neural networks. These regions are inputted into a convolutional neural networks. The convolutional neural network is trained under low illumination conditions using 3D InIm reconstructed images with the objective to perform 3D object recognition. We have demonstrated that utilizing 3D InIm and convolutional neural networks for 3D training and 3D object classification under very low illumination conditions is a promising approach [1].

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Multi-wavelengths digital holography for erosion measurements under extreme environmental conditions inside the ITER Tokamak

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The International Thermonuclear Experimental Reactor (ITER) Project (see Fig. 1) is the next step in the transition from experimental studies of plasma physics to full-scale electricity-producing fusion power stations. It fuses the hydrogen isotopes deuterium and tritium into helium thereby releasing a high energy neutron. In order to start the fusion reaction the temperature has to be about 150 million Kelvin, creating a plasma. Because there is no material that could withstand such high temperatures, the plasma is guided, contactless, by magnetic fields within the vacuum chamber. However, these fields are not fully closed, resulting in partial plasma contact particularly in the divertor region. This leads to wear effects, affecting the overall performance and reliability of the Tokamak and potentially generating metallic dust. Thus, there is a need for the regular measuring of the erosion and deposition at the wall once the Tokamak starts operating. An erosion and deposition monitor able to measure the changes in the surface shape with a depth resolution of 10 μm is planned. The measurement will be done not on the whole internal surface of the Tokamak but on two surfaces of the divertors that endure high rates of erosion and deposition, each of a size of 10x30 cm². Due to the high temperature and radiation it will not be possible to have the measuring system inside the Tokamak, for this reason the measurements will be performed remotely. Hence the opto-electronic instruments (detector, laser, controlling electronics) will be located at a distance of about 40 m from the surface to be measured. We have shown that long distance shape measurements in challenging environmental conditions can be done by two (or multi) wavelength digital holography [1] and thus this technique could be used for the erosion monitoring inside the Tokamak. Fast acquisition of holograms to reduce the influence of strong vibrations persisting inside the Tokamak has been developed.

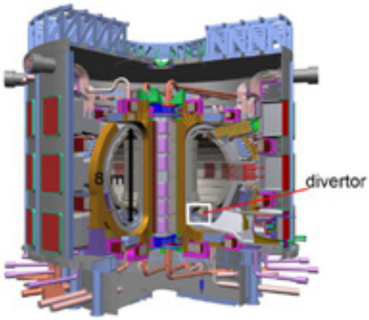

Fig. 1. CAD model of the Tokamak (https://de.wikipedia.org/wiki/ITER)

In order to investigate if the technique will be suitable for shape measurements inside the reactor a sample with tungsten monoblocks each having a size 12x12x5 mm³ was used. The monoblocks have been exposed to very intense heat fluxes in an electron beam facility to study how tungsten behaves under ITER relevant conditions. The object was located on a table at a distance of 23 from the imaging lens. The results of the shape reconstruction are shown in Fig. 2.

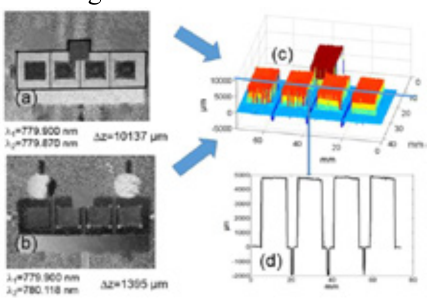

Fig. 2. Shape reconstruction (c) of the tungsten sample from two phase maps (a), (b) obtained from holograms recorded at the wavelengths: : 779.900 nm, 779.870 nm and 779.900 nm, 780.118 nm, respectively. Profile along a line(d).

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Quantum information with multi-core fibers

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Quantum communications (QC) [1] is one of the main areas of the broader field of Quantum Information [2]. The most well-known application of QC is in communication security where two remotely separated parties are able to generate an identical secret key, through a protocol called quantum key distribution (QKD) [3]. Another important application of QC is as the support backbone for future networks of quantum computers, the so-called Quantum Internet [4].

In addition to that, recent advances in optical fiber technology aimed at continuing to support the constantly increasing demand for higher transmission capacity have taken place. The most recent advance in that respect is called spatial division multiplexing (SDM**)** [5]. It takes advantage of the transverse spatial DOF of a light beam in order to multiplex different data streams, thus increasing the overall capacity of the fiber.

Here I will present recent results where a 4-dimensional QKD session took place over 300 m of multi-core fiber, aiming at increasing key generation rate through the use of higher-dimensional states [6]. This was also, at the time, the highest distance that an spatially-encoded quantum state was transmitted over optical fibers. I will also present a quantum random number generator based on measurement-device-independence that is built using a 4-port beamsplitter built by tapering a piece of multi-core fiber [7]. Finally I will show recent preliminary results of the study of propagation of spatial states over few-mode fibers, as well as integration with silicon nitride photonic circuits.

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Multiframe superresolution meets compressive imaging

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Reconstructing a high resolution image from a low resolution image is an ill-posed inverse problem. Multiframe Superresolution (SR) tries to overcome this problem by aiming to artificially reconstruct a high resolution image from a set of low resolution images [1]. Multiframe SR relies on some sort of diversity between every shot, often accomplished by controlled subpixel shifts of the camera system, or from natural motion of the scene—if it can be properly registered. The low resolution images can be either acquired sequentially using a low resolution detector—with the advantage of effectively increasing its resolution—or simultaneously by using a low resolution camera array [2]—with the advantage of reducing the form factor of the imaging system. Overall, SR techniques are related to a different way of capturing the same imaging information using a similar amount of measurement resources than would be required to capture the reconstructed high resolution image. On the other hand, by knowing that natural images are compressible when projected onto an appropriate basis, compressive imaging (CI) aims to reconstruct a high resolution image from a few linear projections of the original scene, relying on the mathematics of compressed sensing (CS) [3]. The compressive imaging projections can be either sequential as in the single pixel camera—with the advantage of being arbitrary and fully random as suggested by CS theory—or simultaneous by using a low resolution detector and exploiting optical multiplexing and coding [5]—with the disadvantage of being deterministic. Overall, each one of the snapshots needed to accomplish multiframe SR can be seen as a set of projection for compressive imaging. Every new shot can reduce the amount of compression requested by the SR problem. In this talk we will discuss how to analyze the diversity provided by every new shot—with pure subpixel shifts, for instance—from a CS theory perspective [6], linking the conditioning number of the matrix operator to be inverted with its mutual coherence parameter. In this context, we will present evidence if it is convenient to increase the diversity by adding a layer of optical coding to enhance the capabilities of a traditional multiframe SR imaging system.

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Using Optical Short Pulse in Optical Engineering

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Ultrashort pulse light beam is an important tool in many areas of science and technology. It is used to study ultrafast phenomena to new imaging modalities. Because of its ultra-broad frequency bandwidth, it can be used to control, manipulate, and characterize light–matter interactions.

Over the recent years, we have played with non-paraxial beams and short pulses to imagine new imaging modalities. However, we also found the ultrashort pulse of a fraction or few optical cycles may change many well-known assumptions in optical engineering. Here a few questions:

- Does the ultrashort pulse will affect the diffraction point spread function?
- Does ultrashort pulse interferometry to test optical component is possible?
- How the far field and near field diffraction are affected by ultrashort pulse duration?
- How vectorial beams are affected under short pulse and non-paraxial conditions?

In this talk, I will try to introduce how ultrashort pulse may open a new area in optical metrology and more generally in optical engineering.

Secure multi-party quantum communication

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Quantum information science breaks limitations of conventional information transfer, cryptography and computation by using quantum superpositions or entanglement as resources for information processing. Here we report on the experimental realisation of three-party quantum communication protocols using single three-level quantum system (qutrit) communication: secret-sharing, detectable Byzantine agreement and communication complexity reduction for a three-valued function. We have implemented these three schemes using the same optical fibre interferometric setup. Our realisation is easily scalable without compromising on detection efficiency or generating extremely complex many-particle entangled states.

TUESDAY, JULY 2

Learning, neural networks and optics

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The topic of learning to execute tasks in optics through training neural networks has a long history [1]. In recent years, the emergence of "deep learning" networks has led to new ideas for how to use learning techniques in the design and operation of optical systems [2,3,4,5,6]. We will present results from this recent activity and describe how deep neural networks can be applied t optical imaging systems.

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High-speed imaging of dynamic and transparent object by parallel phase-shifting digital holographic microscope

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We demonstrated phase imaging of dynamic and transparent object by parallel phase-shifting digital holographic microscopy [1]. Parallel phase-shifting digital holography is a technique capable of single-shot recording of complex amplitude distribution of an object [2,3]. We constructed a vertical microscope of parallel phase-shifting digital holography [4]. In this paper, we demonstrate high-speed imaging of dynamic phase change of air induced by a speaker.

Figure 1 shows the schematic of the microscope. A speaker was set by one of the optical paths of the Mach-Zehnder interferometer of the microscope. A laser operated at 532nm was used for the optical source. We employed a high-speed polarization imaging camera, Photron Fastcam SA-2P [5] to record multiple phase-shifted holograms with a single shot exposure.

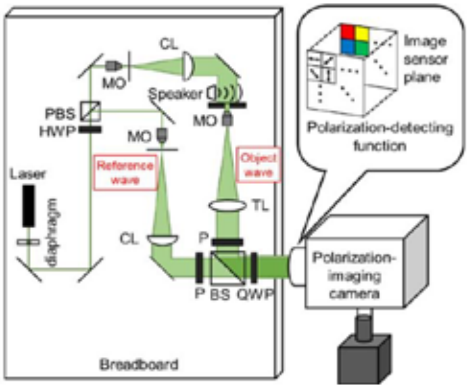

Fig. 1. Schematic of the parallel phase-shifting digital holographic microscope. PBS, polarizing beam splitter; HWP, half wave plate; QWP, quarter wave plate; P, polarizer; MO, microscope objective; TL, tube lens.

We recorded the holograms at 3000 frames per second when the speaker was vibrated with a single frequency of 1000 Hz. We analyzed the change of the pixel value of one of the addresses of the sequence of the phase images reconstructed from the sequence of the holograms. Then the phase oscillated at 1000 Hz. Thus, we confirmed that the constructed microscope successfully records the high-speed phase change induced by the vibration of the speaker.

This study was partially supported by Japan Society for the Promotion of Science (JSPS) KAKENHI Grant-in-Aid for Challenging Exploratory Research.

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Order and porosity increase optical materials' versatility

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Order is always behind pattern formation, which is key to understanding, modelling and prediction in many areas of science and technology such as in photonic crystals. Disruption of order can fundamentally alter their optical properties to such degree that they give rise to new kinds of materials. Porosity on the other hand enables host structures to be mixed with guest materials into composites changing their physical properties.

Order (or the lack of it) and its repercussions can be turned into tools capable to measure the alterations produced when porosity is employed to create new types of materials. Opals and related particulate materials, through templating methods, are apt for the synthesis of composites that enjoy the advantages both of the amounts of order and porosity.

The difficulty of imparting and controlling order in self-assembled materials depends on the shape of the assembling particles, spheres being the easiest. Polyhedra required special care and their colloidal assembly is still subject of intense research [1].

When order is present the optical properties, permit studying for instance the incorporation of minute amounts of water in the host (such as silica or carbon [2] microporous spheres) and its dynamics or turn the system into humidity of dew point sensors [3].

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Nanophotonic interferometric silicon biosensors for label-free and real-time diagnosis of biomarkers

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Photonic biosensors are systems that seize different light-based phenomena for the fast detection and quantification of biomarkers (i.e. molecules or pathogens, whose presence or quantity is an indicator of the onset of a disease). These devices have become critically important as an efficient tool for environmental control and clinical health diagnostics. Among the different photonic biosensors, Silicon photonics biosensors based on evanescent wave sensing principle offer undisputed advantages such as robustness, reliability, high sensitivity and low power consumption.

We have introduced a new type of silicon photonic sensor, the bimodal waveguide (BiMW) interferometric biosensor, which is offering an unprecedented sensitivity while operating under a label-free scheme (detection limit of 10^{-8} RIU for bulk sensing and below 0.01 pg.mm^{2} for surface sensing). It is also prone to miniaturization and multiplexing as is fabricated in compact silicon nitride waveguides contained on chips. Moreover, the simplicity of the BiMW design, based on a common path waveguide, makes the BiMW sensor attractive for mass production since there is no need to use light splitters.

We are using full microfluidics lab-on-chip integration and dedicated biofunctionalization routes of the biological receptors (as proteins or genomic strands) ensuring selectivity, life-cycle, non-fouling properties and reusability of the BiMW biosensor. Moreover, we have demonstrated the suitability of our nanointerferometric technology for the diagnostics, with extremely sensitivity and selectivity and directly in human fluids, of: infectious bacteria (at few cfu/mL), early detection of colorectal cancer, fast detection of Tuberculosis in patients´ urine or the analysis of microRNA biomarkers at aM level related to bladder cancer progression, among others.

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Near-to- & on-eye displays

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Compact near-to-eye displays (NEDs) with functions of augmented reality, which looked like a bit of fantasy some years ago, are becoming more and more realistic nowadays. Numerous medical and military applications, telecommunication, transportation and game industry are only a few areas where NEDs are of inestimable value. Despite the dramatic advances in development of NEDs [1, 2], expectations for NEDs with ergonomics comparable to eyeglasses have yet to be met [2].

The key element of NED is either a tiny projector incorporated into glasses or a microdisplay located a few centimeters from the eye. In attempts to decrease sizes of the displays and to increase mobility, the possibilities of integration of an image source into a contact lens have been studied [3, 4]. However, how to see an image source that located at the immediate vicinity of the eye? Recently, we have introduced a way to overcome this difficulty [5-7]. It was demonstrated that a liquid crystal microlens array can reach the optical power needed for producing a virtual image of the image source at distance 25 cm and more from the eye. However, implementation of the microlens array is associated with two problems: 1) correct conjugation of the image provided by the microdisplay with the retina of the eye, and 2) existence of light leakage to a microlens from adjacent pixels that causes the image blur. Our work is devoted to consideration of these problems and their possible solutions.

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Optics of conducting polymers

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Since the discovery of conducting polymers, their electronic structure and optical properties have attracted massive attention, both experimentally and theoretically. Conducting polymers are utilized in a number of applications including the organic light-emitting diodes, electrochromic displays, photovoltaic devices, electroluminescent devices, nonlinear optic devices, and many others. The electronic and optical properties of conducting polymers are related to the conjugated nature of their backbones and to the formation of polarons and bipolarons that represent singly and doubly charged quasiparticles, respectively, that are localized along the polymer chains due to a strong electron−phonon coupling. One of the most important conducting polymers is poly(3,4-ethylenedioxythiophene) (best known as PEDOT), which plays the same role in organic electronics as *e-coli* in biotechnology and microbiology, and *Drosophila* in genetics and developmental biology.

In spite of the long-term use of this material for electronics and optical applications, the fundamentals of its optical properties remain poorly understood. The predictions based on semi-empirical approaches developed in eighties are still commonly used for discussion of the electronic structure and interpretation of the optical absorption of PEDOT and other conducting polymers. It has been recently realized that modern approaches based on the Density Functional Theory (DFT) and the time-dependent (TD) DFT predict the electronic structure and optical transitions in conducting polymers that are qualitatively different in comparison to the above-mentioned earlier studies.

In the present paper we investigate the electronic structure and optical absorption spectra of PEDOT for different doping levels using the DFT and TD-DFT approaches.[1] We demonstrate that the DFT-based predictions for the polaronic and bipolaronic states and the nature of corresponding optical transitions in PEDOT are qualitatively different from the widely used traditional picture based on semi-empirical pre-DFT approaches that still dominate the current literature. Based on the results of our calculations, the experimental Vis/NIR absorbance spectroscopy is re-examined and a new interpretation of the measured absorption spectra that is qualitatively different from the traditional interpretation is provided.

The findings and conclusions concerning the nature of polaronic and bipolaronic states, band structure and absorption spectra presented for PEDOT, are generic for a wide class of conducting polymers (such as polythiophenes and their derivatives) that have similar structure of monomer units.

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100Gbaud pulse amplitude modulation links for optical interconnects

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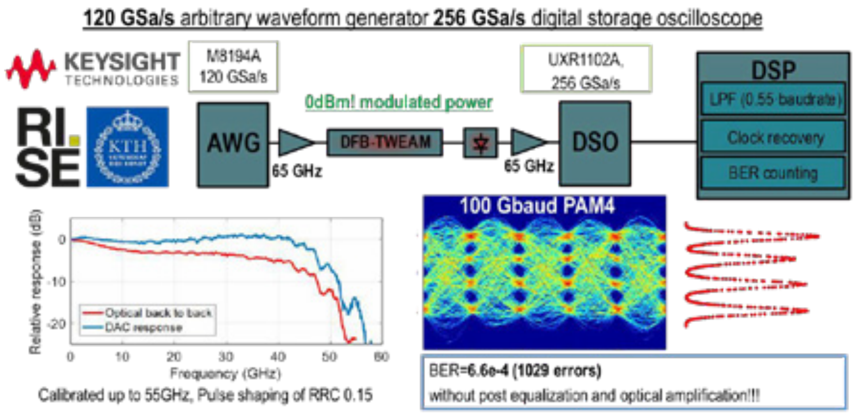
Emerging technologies and applications for Datacenters, 5G mobile systems, medical monitoring, traffic safety and society security are stretching the requirements for seamless connectivity. Technical and economic challenges arise to keep up the bandwidth density and scalability [1]-[4].

We review experimental demonstrations of 100 Gbaud 4-level pulse amplitude modulation (PAM) and 8-level PAM (PAM8) links in C-band for short reach optical interconnects. We demonstrate 100 Gbaud PAM4 transmission over 400 meters long standard single mode fibre (SSMF) without optical amplification and without post-equalization.



We also achieve 300 Gbps line rate with 100 Gbaud PAM8 after 400 meters with post- equalization which is compelling improvement compared to the previous work [5].

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High spectral efficiency transmission based on frequency combs

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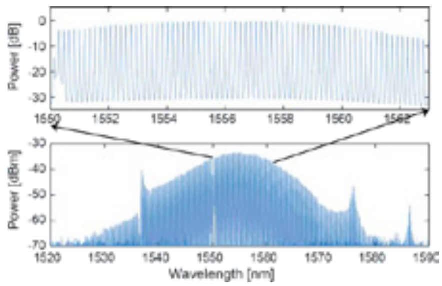
Optical frequency combs, despite being a fascinating research area in itself with numerous applications [1], are very promising light sources for high capacity fiber optical communication systems [2]. Today's wavelength-division multiplexed fiber links can consist of hundreds of wavelength channels in a single fiber, each requiring an individual transmitter laser complete with wavelength and temperature stabilization. To replace these lasers with a single comb source may thus lead to great system simplifications and power savings.

Moreover, the fact that the individual lines in a comb are phase-locked will lead to several additional improvements. First, one may pack locked channels more densely than freee-running lasers, requiring less guard bands between channels, and improving the spectral efficiency.

Secondly, one may use the coherence between the lines to *jointly* detect the phase of coherently received data, which increases fidelity and can improves spectral efficiency by enabling the use of higher-order modulation formats [3].

Comb sources can be made compact with silicon photonic integration capabilities. As an example, a silica disc can be used, which is still fiber compatible thanks to a whispering gallery mode induced by tangential fiber coupling. The resulting comb, shown in the figures, is, approximately, a soliton pulse. In [4] we use this comb to demonstrate generation and transmission of 16-, 64- and 256-ary quadrature amplitude modulation. The line spacing was 22 GHz, and the symbol rate 21.5 Gbaud, enabled by the frequency stability of the comb. Independent lasers would have required significantly larger (10x-30x) guard bands between channels. In total, this comb enabled 12 Tb/s of data were transmitted over 2000 km at spectral efficiencies ranging from 12 to 6 bits/s/Hz. These are the highest spectral efficiencies demonstrated with integrated comb sources.



Acknowledgements: The results described in [4] were a collaboration by transmission experiments at the Chalmers Fiber optic research center (FORCE) in collaboration with Prof. K. Vahala's group at Caltech group who realized the comb source.

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Holographic 3D Stimulation and Observation for Neuroscience

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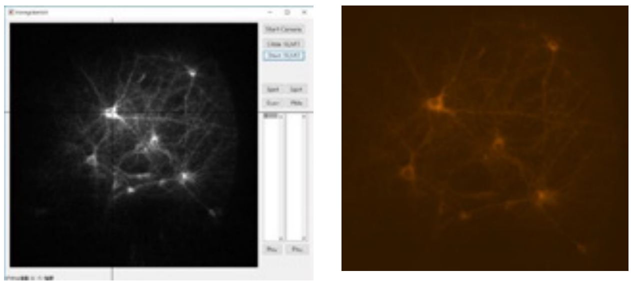
Optogenetics is one of the hot topics of neuroscience and is one of the optical manipulation tools of cell activity and cellular network of the brain. To achieve a higher level of optical manipulation, a spatial and temporal optical irradiation to individual cells is required. We have proposed a new functional optical microscope for neuroscience[1]. In the proposed microscope, two functions those are the holographic illumination to generate the multiple focused spots and the holographic observation of fluorescence distribution to monitor the cell status after the irradiation.

In the holographic illumination, multiple 3D focused spots are designed by phase-only modulation by the Fourier transform of the phase distribution displayed in the spatial light modulator. Optimization of phase pattern based on iterative process is presented. Figure 1 shows a graphical user interface to select the target cells to be irradiated and the fluorescence image. In the feasibility experiment, simultaneous generation of focused spots is confirmed by scanning the focal plane of the observation by using an electrically tunable focal lens. In the presentation, some required techniques for cell manipulation are discussed.



(a) (b)

Fig. 1. A holographic stimulation to the cells. (a) Graphical user interface and (b) fluorescence image.

In the holographic observation of 3D fluorescence distribution, the development of incoherent digital holography is required. Fluorescence light is incoherent or partially coherent light. Therefore, self-interference by dividing two light waves of fluorescence light is used. For embedding the incoherent digital holography to the optical microscope, a compact and simple optical configuration is required. We proposed a common-path geometry with off-axis incoherent digital holography [1-3]. In this setup, the modulated fluorescence light by a lens function with a grating and the unmodulated light can make the interference pattern. We presented feasibility experiments using fluorescence beads and cells of mouse brain.

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Optical Biomimetics – Polarization Studies of Scarab Beetles

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Skylight, underwater light and other natural radiation is often polarized to some extent. Polarization of light can also be generated due to surface reflections, for instance from animals and plants. In most cases the state of the polarized part is linear but there are examples from nature where reflections show elliptical or even circular polarization. This is for instance the case for reflections from some scarab beetles having helicoidal chitin nanostructures, so-called Bouligand structures, in their exoskeletons.

With our main experimental technique, Mueller-matrix spectroscopic ellipsometry (MMSE), we have measured several beetles from the *Scarabaeoidea* subfamilies *Cetoniinae* and *Rutelinae*. Full 4x4 Mueller matrix data were recorded as a function of wavelength $\lambda \in$ [245, 1000] nm, incident angle $\theta \in$ [20, 75]º and sample orientation $\varphi \in$ [0, 360]º. From these measurements we can specify the $\lambda\theta$-regions for which the reflected light has a high degree of circular polarization P_c. As a comparison, Fresnel- based simulations of the optical response from twisted chitin structures were performed giving the Mueller matrix as a function of λ, θ and φ. The simulated data corresponds well to the measured data. Subsequent non-linear regression analysis gives more detailed information of the beetle exoskeletons and makes it possible to specify trends and differences among the observed beetle species. The data is furthermore analysed using dispersion studies giving helicoidal pitch profiles, as well as matrix decompositions to describe the structures as a combination of basic optical elements.

Biomimetic approaches to produce artificial structures with polarization properties similar to the beetles will also be presented. A first example is spiral structures consisting of magnetron sputtered InAlN nanorod films having an orientation dependent internal composition gradient in the crystalline structure. Samples with different pitch and layer thickness and with right-and left-handed chirality were grown producing structures reflecting both left-handed and right-handed near-circular polarized light at different wavelengths and incidence angles. A second example is free-standing nanocrystal cellulose fabricated using slow evaporation of aqueous suspensions of cellulose in a nematic chiral liquid crystal phase. MMSE transmission measurements show high P_c and the circular dichroism and optical rotation are evaluated.

(a) (b) (c) (d)

(a) Schematic view of the Bouligand structure showing the pitch Λ, (b)-(d) Photos of the beetle *Chrysina chrysargyrea* taken (b) without polarizer, (c) with a left-circular polarizer and, (d) with a right-circular polarizer in front of the camera.

WEDNESDAY, JULY 3

Optimizing measurements for task specific compressive sensing

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While the theory of compressive sensing has been very well investigated in the literature, comparatively little attention has been given to the issues that arise when compressive measurements are made in hardware. For instance, compressive measurements are always corrupted by detector noise. Further, the number of photons available is the same whether a conventional image is sensed, or multiple coded measurements are made in the same interval of time. Thus it is essential that the effects of noise and the constraint on the number photons must be taken into account in the analysis, design and implementation of a compressive imager. In this paper, we present a methodology for designing a set of measurement kernels (or masks) that satisfy the photon constraint and are optimum for making measurements that minimize the reconstruction error in the presence of noise. Our approach finds the masks one at a time, by determining the vector which yields the best possible measurement for reducing the reconstruction error. The sub-space represented by the optimized mask is removed from the signal space, and the process is repeated to find the next best measurement. Results of simulations are presented that show that the optimum masks always outperform reconstructions based on traditional feature measurements (such as principle components), and is also better than the conventional image in high noise conditions.

Nonlinear microscopy of nanostructures using cylindrical vector beams

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Nonlinear optical processes are sensitive to the structural and symmetry properties of materials and therefore allow for unique characterization capabilities for new materials. In particular, nonlinear processes provide completely new contrast mechanisms for microscopy. Such capabilities are augmented by relying on polarization properties of focused optical beams, where the polarization vector can have three-dimensional orientation and is also spatially inhomogeneous. In this paper, we summarize our results on the use of so-called cylindrical vector beams on the characterization of nanostructures, including both metal- and semiconductor-based structures [1].

The prime examples of cylindrical vector beams are radially- (RP) and azimuthally-polarized (AP) beams. Of particular importance is the fact that, in focusing, RP beam gives rise to a strong longitudinal electric-field component at the geometrical focus. In contrast, focused AP beam maintains a strictly transverse electric-field distribution in the focal volume, thus mimicking the structure of the incident beam before focusing. These properties are particularly beneficial for the characterization of nano-objects with complex shapes or arrangements.

In our initial work on this topic, we have shown that second-harmonic generation microscopy with cylindrical vector beams has superior sensitivity to the morphology of individual metal nanoparticles [2]. Subsequently, we have shown that efficient coupling of incident light to metal nano-objects requires tailored focal fields matching the modes of individual particles [3,4] or oligomers consisting of several nanoparticles [5].

We also used cylindrical vector beams to characterize the crystal structure of semiconductor nanodisks [6] and to couple light to vertically-aligned semiconductor nanowires [7]. These capabilities can also be turned around, i.e., nanowires can be used to probe the longitudinal field components of advanced polarization states in three dimensions.

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Fast chemical imaging via compressive Raman microscopy

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Raman imaging is recognized as a powerful label-free approach to provide contrasts based on chemical selectivity. Nevertheless, Raman-based microspectroscopy still have drawbacks. The first issue is on data acquisition: the inherent high data throughput in Raman microspectroscopy poses challenges for dynamic and large-scale imaging, together with its subsequent data storage. The second issue is the slow data workflow methodology: the overwhelmingly large data sets need post-processing to allow for a more useful and straightforward presentation (typically limited to the number of different target chemicals).

Compressive sensing has shown a paradigm shift approach where one can obtain accurate information from fewer samples than assumed by Nyquist-Shannon sampling theorem. A key concept in compressive sensing is to recognize that data sparsity can be exploited to reconstruct data that has been considerably undersampled.

In this contribution, I will introduce the concept of compressive Raman imaging: by exploiting the sparsity [1] and redundancy [2] in the Raman data sets, one can considerably simplify and speed up the spectral image acquisition. I will discuss the different ways of performing compressive Raman, in particular focusing on challenges for bio-imaging, and how we recently tackled them. With these outcomes, compressive Raman imaging soon may be routinely used by non-specialists in vibrational spectroscopy, that is in a “blind” manner, due to the simpler workflow provided by the compressive Raman imaging framework.

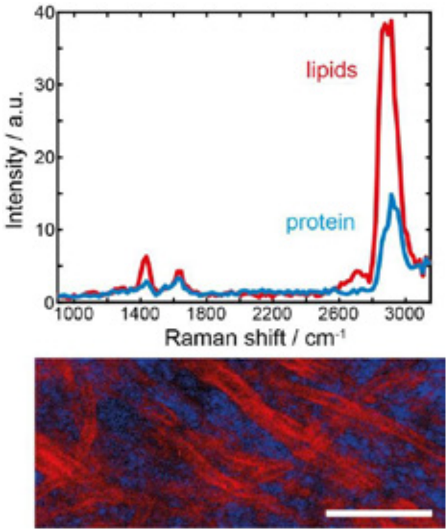

Fig. 1. Representative results of the compressive Raman framework applied for imaging of biological specimens (brain tissues). (upper panel) Principal component spectra. (lower panel) Chemical images based on the principal components spectra (red= lipids, blue=protein)

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Nonparaxial polarization: basic elements and application in fluorescence microscopy

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When studying nonparaxial light, all three electric field components must be considered, and standard concepts from paraxial polarization, such as Stokes parameters, the Poincaré sphere and the Pancharatnam-Berry geometric phase, must be extended. For paraxial partially polarized light, the standard Stokes parameters are the coefficients of the expansion of the 2x2 polarization matrix in terms of the three Pauli matrices plus the 2x2 identity. These parameters lead to a representation of polarization as a point inside a unit sphere, the Poincaré sphere, in an abstract three-dimensional space. Fully polarized paraxial fields correspond to points over the surface of this sphere. A sequence of polarization transformations leads to a geometric phase that is connected to the enclosed solid angle within the Poincaré sphere.

For nonparaxial fields, on the other hand, the polarization matrix is 3x3 and the basis of nine Hermitian traceless 3x3 matrices needed to expand it are the eight Gell-Mann matrices plus the 3x3 identity. The resulting coefficients have been proposed as nonparaxial generalizations of the Stokes parameters [1], which can be characterized by a point inside a hypersphere in eight dimensions, with full polarization corresponding to the hypersphere's hypersurface.

This presentation has two parts: i) an application of this 8D Stokes vector in fluorescence microscopy, and ii) a simplified representation for polarized light where, instead of a point over a 7-sphere, only two points over a unit 2-sphere in the physical 3D space are required, and where geometric phase corresponds to an enclosed solid angle.

Fluorescence microscopy. By using a tailored birefringent mask at the pupil of a microscope, it is possible to determine not only the transverse position of fluorescing molecules but also their longitudinal coordinate, 3D orientation, and even their state of vibration. The key is the decomposition of the measured images (whose shapes encode orientation and defocus) in terms of a basis of reference point spread functions, the result of which is the longitudinal coordinate and the nine nonparaxial Stokes parameters of the field emitted by the molecule. From these parameters, the molecules' orientation and state of vibration can be retrieved [2].

Geometric phase. For monochromatic nonparaxial light, the nine Stokes parameters are redundant and only four numbers are needed to specify the shape and orientation of a planar ellipse in 3D. We show that these numbers can be represented by two points over a unit sphere's surface by incorporating aspects from both the Majorana [3] and Poincaré representations (hence the name Poincarana), where enclosed solid angles correspond to geometric phases [4].

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Diffraction-free fields on incoherent background

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To the most extensively studied partially coherent sources are of the so-called Schell-model type which give rise to uniformly correlated partially coherent fields [1]. The Schell-model sources can be readily realized in the laboratory using random phase spatial light modulators [2] or taking advantage of coherence shaping of free space propagating fields generated by incoherent light sources [1].

Although theoretical exploration of non-uniformly correlated partially coherent sources was initiated more than a decade ago [3], only a few examples of such sources have been studied in detail to date [3-5]. This is because laboratory realization of non-uniformly correlated partially coherent beams has met with formidable difficulties. In fact, only one class of non-uniformly correlated partially coherent beams, composed of just two uncorrelated coherent modes, was experimentally realized until fairly recently [6].

Diffraction-free fields carry special promise for information transfer in free-space optical communications. Generic properties of diffraction-free optical fields have been theoretically elucidated and the cross-spectral densities of a wide class of such fields, the so-called dark and antidark diffraction-free beams, has been derived in a closed form a decade ago [4]. These diffraction free fields manifest themselves as optical dips or bumps against the (partially) incoherent background.

In this work, we report the first, to our knowledge, generation of dark and antidark diffraction-free sources using the coherent-mode superposition of Bessel modes [7]. Each individual mode is generated by a laser beam, transmitted through a computer-generated hologram loaded to a spatial light modulator. Dark or antidark diffraction-free fields are then obtained by averaging over temporal sequences of their coherent modes. We next introduce theoretically a class of accelerating diffraction-free fields on incoherent background and discuss their salient features. We conclude with the outlook for generating generic polychromatic diffraction-free fields on incoherent background and we position our work into the context of recent efforts to generate such fields in the laboratory.

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Twisted Laguerre-Gaussian Schell-model beam and its orbital angular momentum

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We introduce a twisted Laguerre-Gaussian Schell-model (TLGSM) beam, carrying both vortex phase and twist phase, which exhibits unique propagation properties. Furthermore, we investigate the orbital angular momentum (OAM) of the TLGSM beam. Figure 1-2 shows the evolutional properties of the spectral density and spectral degree of coherence (SDOC) of the TLGSM beam passing through a paraxial ABCD optical systems.

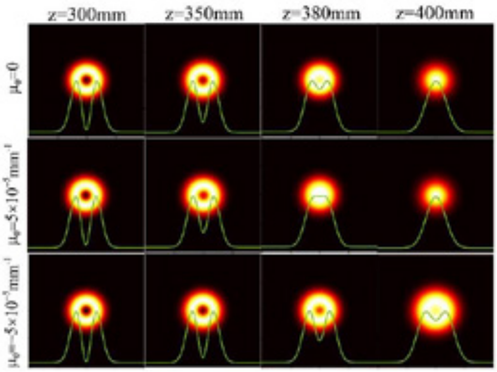

Fig. 1. Density plot of the normalized spectral density of TLGSM beams with l=1 for different values of the twist factor μ_0 at several propagation distances after passing through a thin lens (f=400mm).

One found that that the handedness of vortex phase and twist phase affects the spectral density and the SDOC during propagation. When the handedness between two phases is opposite, the beam profile transition from dark hollow shape in the source plane to Gaussian shape on propagation is accelerated, and the side rings of the SDOC in the far field is enhanced, when the handedness of two phases is the same, these situations are reversed.

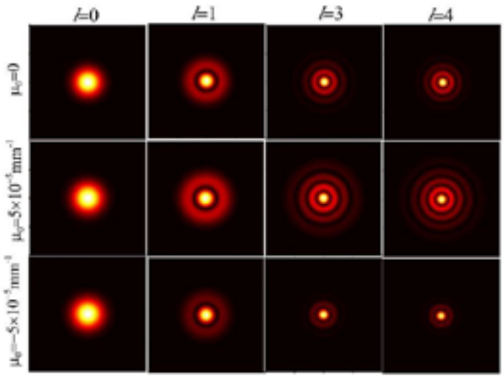

Fig. 2. Density plot of the spectral degree of coherence of the TLGSM beam with different topological charges l in the focal plane of the lens for three different values of twist factor.

The time-average OAM flux of the TLGSM beam in the source plane is obtained as [1],

$$J_z = n\hbar[l - 2\mu_0 k\sigma_0^2 - 2\mu_0 k\sigma_0^2 |l|] \quad (1)$$

It is found that the vortex phase's and twist phase's contributions to the OAM are interrelated, which greatly increases the amount of OAM.

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Utilizing Quantum Correlations in Practical, Noise Resilient Imaging Modalities

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Optical target detection has been receiving increasing attention recently owing to many emerging applications in the domains of human/machine interaction, LIDAR, and non-invasive biological imaging, amongst others. Conventionally, the sensitivity of optical target detection could be improved by increasing the source brightness, detector sensitivity, improving the throughput of the optical setup or using more complicated protocols such as coherent detection.

Different practical versions of quantum enhanced imaging have been proposed in the past decade to bridge the gap between theory and practical application. It was proposed by Sikat et al. [1] and Tan et al. [2] that a quantum illumination protocol could be implemented with only gaussian states as the light source and an optical parametric amplifier as the receiver, yet still retain enhanced performance beyond the classical regime. Such protocol has already been experimentally demonstrated [3], however, the measurement time is extremely long and the implementation is nontrivial: a phases sensitive joint measurement of both the probe and reference photons at an optical parametric amplifier is necessary to assess their nonclassical entanglement to decide the presence or absence of the object. Therefore, the strict temporal- phase synchronization between the probe and the signal photon has to be maintained, which necessitate the using of quantum memory and careful dispersion compensation. Such technical complexity poses a severe limitation in ranging and sensing applications where the temporal- phase synchronization is likely to be deteriorated by unknown and uncontrollable environmental factors such as mechanical vibration moving targets and polarization instability.

In our approach we utilize intensity correlation based target detection protocol, where integrated quantum light sources provide performance enhancement comparable to bulk optics and several additional advantages. Operation of the chip source becomes possible remotely and in applications where the quantum light source needs to be placed in physical proximity of the desired target (particularly useful in quantum-enhanced microscopy), due to its small form factor. The results presented in this talk will demonstrate how such emerging imaging modalities can yield the exceptional performance by using on-chip quantum light sources in real-world scenarios, and pave the way to practical application of imaging technologies which are enhanced by quantum correlations in low-brightness, high-noise, and lossy environments.

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Vector wave beating

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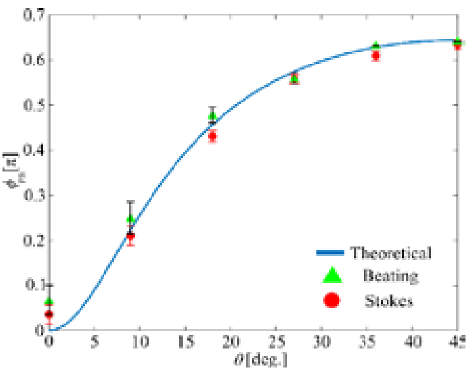
Beating is a temporal interference phenomenon in which waves of different frequencies form a superposition with periodically varying properties. Scalar wave beating, frequently encountered in acoustics and optics, produces a periodic intensity distribution. With vector waves, also – or only – the polarization state may change periodically giving rise to new effects that include the Pancharatnam-Berry geometric phase and polarization-state dependent dynamic phase.

Let $\mathbf{E}(t) = \mathbf{E}_1(t) + \mathbf{E}_2(t)$, where $\mathbf{E}_m(t) = \mathbf{E}_m \exp(-i\omega_m t)$, $m = \{1,2\}$, are waves of frequencies ω_m and vector amplitudes $\mathbf{E}_m$. The polarization state of $\mathbf{E}(t)$ is periodic with period $T = 2\pi/\Delta\omega$, where $\Delta\omega = \omega_2 - \omega_1 > 0$. Hence $\mathbf{E}(t_0)$ and $\mathbf{E}(t_N)$, where $t_N = t_0 + T$, are in the same polarization state and their phase difference [1] is $\Delta\phi = \arg[\mathbf{E}^*(t_N)\cdot\mathbf{E}(t_0)] = \phi_{PB} + \phi_{dyn} = \omega T \pm \pi$, where $\omega = (\omega_1 + \omega_2)/2$ [2]. Here ϕ_{PB} is the geometric (Pancharatnam-Berry) phase arising from polarization variations and ϕ_{dyn} is the dynamic phase due to propagation. Explicitly [2] (see also [1])

$$|\phi_{\mathrm{PB}}| = \pi - \pi \frac{|S_0' - S_0''|}{|\mathbf{P}' - \mathbf{P}''|}, \tag{1}$$

where S_0 and $\mathbf{P}$ are the intensities and Poincaré vectors of the waves (denoted by primes). Thus, the geometric and dynamic phase both depend on the wave polarization states, while their sum remains constant. The sign of ϕ_{PB} is given by the direction of polarization rotation.

The geometric phase may also be evaluated by determining how the phase of $\mathbf{E}(t)$ accumulates over a period T while continually subtracting the dynamic phase [2]. It is found that ϕ_{PB} depends on the intensities $S_0' = |\mathbf{E}_1|^2$ and $S_0'' = |\mathbf{E}_2|^2$ of the two waves and the visibility of the temporal intensity variations of the superposition wave [2].



We have employed both approaches to assess the phase ϕ_{PB} [2]. An acousto-optic deflector creates a frequency-shifted beam from a green diode laser and suitable detectors allow the measurement of the polarization state and the beating visibility of the combined beam. Figure 1 shows the theoretical and experimental results when $S_0'/S_0'' \approx 2.1$ and the angle between the linear polarizations is 2θ.

Fig. 1. Theoretical and measured geometric phase ϕ_{PB} in the beating of two linearly polarized waves [2].

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Polarization of light porpagating through transparent wood

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Transparent wood (TW) was originally introduced a few decades ago for the purpose of investigation of internal wood structure [1]. Later on, the material has found new areas of research interest and potential applications, for example, in the construction industry with the focus on smart buildings [2-4] and photonics [5-7]. TW is a bio-organic material produced from a natural wood via a few steps of chemical treatment: delignification (removal of the light absorbing component from a wood), and infiltration of the porous wood template with a polymer of refractive index matching the average refractive index of wood [2, 7].

Along with high optical transparency, the material is simultaneously highly scattering [8] and structurally anisotropic medium due to well-preserved wood structure. The internal hierarchical structure of the TW influences the polarization of light propagating through the material. In particular, unpolarized light becomes partially polarized (with polarization degree of 50%) after propagating through the TW. On the other hand, the degree of polarization of initially totally polarized light decreases. This decrease of polarization degree is strongly dependent on the mutual orientation of wood (in particular, its structural components) and polarization of incident light, where structure features on both micro- and nano-scales contribute to the polarization change. For extreme cases transmitted light is either almost totally polarized (with polarization degree of 85-90%) or unpolarized (with polarization degree of 2-5%).

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Ghost imaging in the temporal domain

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Ghost imaging is an unconventional imaging technique that generates high resolution images by correlating the intensity of two light beams, neither of which independently contains useful information about the shape of the object. It has been shown that ghost imaging has great potential to provide robust imaging solutions in the presence of environmental perturbations. Originally demonstrated in the spatial domain with entangled photons, ghost imaging has been subsequently extended to the use of classical incoherent light sources. We will review our recent work on ultrafast ghost imaging in the temporal domain opening up new possibilities for ultrafast imaging in spectral regions where sensitive and/or fast detectors are not available and in particular the mid-infrared or THz range.

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Phase space models for wave propagation through disordered media

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We employ a phase space analysis to investigate, and better understand, the field propagation through systems involving disordered media. We show that phase space formalism increases the intelligibility of such system and can help their optimization. Using the phase space analysis, we explain a random screen model that we introduced recently which offers a useful model for the tilt-shift optical memory effect. We also show the utility of the phase space representation to understand and evaluate the performance of lenses imaging system using diffusive elements that we recently have developed.

Asymmetric Free-Space optical link using a modulating retro-reflector

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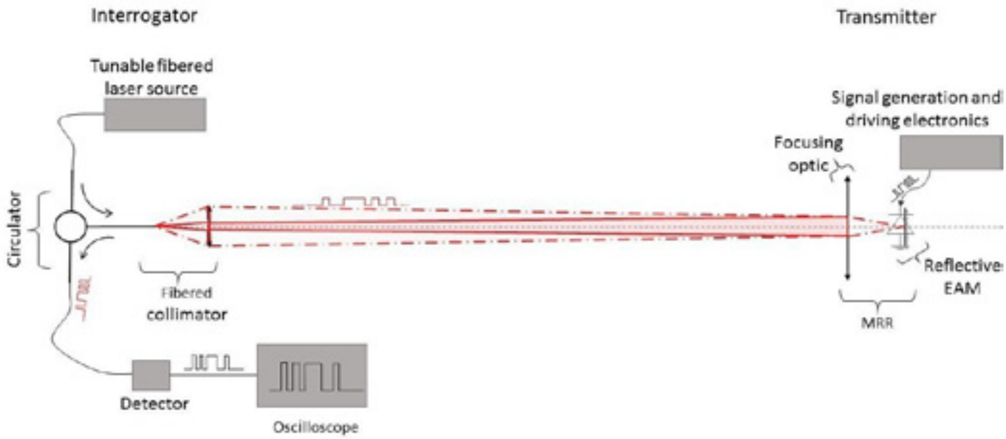
Free-space optical communication is a compelling point-to-point communication technology. Already used for ground-to-ground communication, it has a lot of potential for ground-to air, ground-to-space, air-to-space and space-to-space communication. Compared to radio waves, optical links present a higher directionality, providing better confidentiality. In addition, optical links do not need to deal with an already crowded radio frequency spectrum.

Asymmetric communication architectures are of particular interest for applications in which one of the peers needs to be low power and is the one sending most of the data.

We present our work on asymmetric free-space optical communication links using an electroabsorption modulator at 1550nm integrated in a retro-reflector. Device designs and characteristics are discussed in relation to some applications listed above, including the choice of the appropriate semiconductor material system, device sensitivity towards temperature and radiations, We also elaborate on the system design, both in term of optics, impedance matching, strategies to minimize power consumption, and data encoding. Results of a data transmission link are also presented.



(1) Illustration of an asymmetric free-space optical communication link

(2) Pictures of segmented electroabsorption modulators

The shape of light: how to measure, control and compute complexity?

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We review a selection of recent results where applications of concepts that harness the "shape of light" in spatial or temporal domain have been applied widely to yield significant advances in areas such as computer-vision sensing with digital holography, spatial shaping of complex laser beams and photonic neural networks.

Computer vision is a powerful contact-less measurement tools successfully applied in numerous domains of application, where depth of field and working distances are constrained by the imaging magnification chosen. The use of pseudo-periodic patterns on the target of interest overcomes these usual computer-vision limitations leading to sub-pixel resolutions and making the absolute measurement range independent of the field-of-observation of the imaging system [1]. The approach was also validated using digital holography as imaging method with a tremendous enlargement of the allowed working distance range [2], and seems very well suited to diverse application needs in the micro-robotic and biomedical domains.

Principles of digital holography can be used also for spatial shaping of complex laser beams such as Bessel, Airy or arbitrary beams using liquid crystal spatial phase modulators (SLM). Applications in micro&nano-machining by non-diffracting ultrashort laser pulses in various materials have been proposed during recent years [3]. This will also open new perspectives for applications of complex beams for applications in microscopy, optical coherence tomography or ultrafast physics.

Photonic systems have revolutionized the hardware implementation of Recurrent Neural Networks and Reservoir Computing, in particular [4]. The fundamental principles of Reservoir Computing strongly facilitate a realization in such complex analog systems. Especially delay systems, which potentially provide large numbers of degrees of freedom even in simple architectures, can efficiently be exploited for information processing. We also demonstrated learning in large-scale neural networks with numerous nonlinear nodes in an architecture using SLM [5]. This last scheme is fully parallel and the passive weights maximize energy efficiency and bandwidth.

In high-tech areas such as micro-robotics and photonics, measurement requirements are increasing in terms of high resolution and their controls are based on multi-scale and complex parameters. Increasingly real-time processing remains a big challenge for future applications, where next generation of systems will need to implement new hardware architectures, maybe based on photonic neural networks.

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THURSDAY, JULY 4

Integrated Nanophotonics Technology and Applications

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The current optical technology is costly, bulky, fragile in their alignment, and difficult to integrate with electronic systems, both in terms of the fabrication process and in terms of delivery and retrieval of massive volumes of data that the optical elements can process. The integration of photonic systems requires miniaturization of the optical components, similar to the effort that has led to the extensive miniaturization in electronics. For applications involving a photonics layer between different components on the same chip, the photonic components must be comparable in size to the electronic components, and minimally interfere with each other when densely packed. By taking advantage of advances in lithographic tools predicted to reach features as fine as 11 nm by 2020, it is possible to arrange deeply subwavelength features in a patterned material composition to act as a metamaterial with space variant polarizability. Our most recent work emphasizes the construction of optical subsystems directly on-chip, with the same lithographic tools as the surrounding electronics. Such future systems, further require the discovery of new technologies that can operate not only at ultrafast rates (<1 ps), but also at extremely low energies, and with low levels of insertion loss. Additionally, future technologies will need to be highly compact, as well as resilient to temperature change. Moreover, the device designs should provide scalability with respect to the operating wavelength, and the optical carrier should be allowed to vary in a broad spectral range to support the necessary aggregate information bandwidth. As specific examples of our most recent work towards these goals, we will discuss nonlinear optical devices for second-harmonic generation in non-stoichiometric, silicon-rich nitride films [1-3], chip-scale integrated Fourier Transform Spectrometer [4] and programmable phase modulation of free-space modes at GHz rates exploiting near-field interactions between surface plasmons and materials with an electrooptic response [5].

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Light-field optics and reconstruction of 3D space

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Light field optics is a theorem in which rays in space are recorded on 2D data as they are and they are reconstructed from these captured 2D data. Then a 3D volume image is transformed from these 2D data shown on a flat display using light field display. This paradigm theorem of transformation is similar to holography though light field optics is based on geometric optics not on diffractive optics. Compared to holography, in light field display, resolution decrease in reconstructing volume 3D image from original 2D data is small but ability of depth reconstruction is inferior; a light field display reconstructs 3D image nearby its screen and range of depth in which it reconstructs 3D image is limited.

So, we developed aerial 3D display combining a light field display with aerial imaging device. And we produced a 3D space reconstruction system modifying this aerial 3D display. The former system displays 3D volume image in air, shifting a reconstructed volume image near the screen to air. And the latter is a system which reconstructs conditions of rays in space as they are or as a light field camera has captured.

I introduce these new trial applications of light field display we are studying now and talk about a few other possible applications for 3D reconstruction.

Aberration-insensitive microscopy using interferometric ghost-like imaging

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Imaging techniques based on optical correlation measurements and using spatially incoherent illumination have been shown to be able to reduce the effect of optical aberrations. One of such techniques is classical ghost imaging. It is based on spatial intensity correlations in two optical beams of which one is transmitted through the object. The image is obtained from the correla- tion measurements even though the object beam is analyzed with a bucket detector [1]. Another correlation-based technique with spatially incoherent illumination is full-field optical coherence tomography using optical interference instead of intensity correlations for three-dimensional imaging of back-scattering objects [2]. This technique utilizes light with short longitudinal co- herence length and is insensitive to weak aberrations (limited in the wavefront shifts by the coherence length).

In this work, we introduce an interferometric ghost-like imaging microscopy that is insensitive to severe optical aberrations. This capability stems from a large longitudinal coherence length of illuminating light. The approach makes use of a Mach-Zehnder interferometer for transmis- sive objects [3] or a Michelson interferometer for reflective and back-scattering objects. The technique yields sharp and non-deformed microscope images even if the objects are screened by an optical diffuser that destroys the intensity im- age. Furthermore, not only amplitude, but also phase objects can be im- aged with high resolution in the presence of strong aberrations. Figure 1 il- lustrates imaging of two microscopic logos of Aalto University using a system in the Mach-Zehnder configuration. The logo shown in Fig. 1a is etched through a metal film, while the logo in Fig. 1b is a phase object in the form of an elevated polymer film. The second column in Fig. 1 shows the intensity images destroyed by an optical diffuser, while the third column exhibits the re- trieved interferometric images which are nearly perfectly sharp. The approach may find appli- cations in optical microscopy and a variety of interferometric devices.

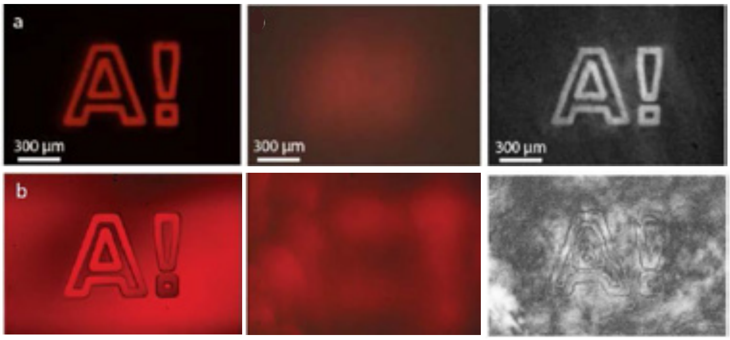

Fig. 1. Imaging of (a) an amplitude object and (b) a phase object in the presence of strong aberrations. The aberrated intensity images are shown in the second column, while the retrieved interferometric images are presented in the third column.

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Mid-Infrared ranging facilitated through Intra-Cavity Up-Conversion

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There are several attractive features with a mid-infrared (MIR) LIDAR utilising photon counting techniques, such as range resolved gas concentration measurements [1] and higher transmission through certain media. Photon counting LIDARs have been around for a long time [2], but have been limited to shorter wavelengths. In more recent years, photon counting LIDARs at longer wavelengths around 1.5 µm have emerged. These are often based on either cooled detectors [3], or utilising InGaAs detectors [4]. However, the direct detectors in the MIR are limited in wavelength to about 2.5 µm, due to their low photon energy, and require to be cooled to low temperatures or have worse temporal resolution, dark count rate and dead-time than their equivalent Si-based detectors.

A solution to be able to benefit from both the MIR LIDAR features and the Si-based detectors is to do the LIDAR in the MIR and then up-convert the pulses through sum-frequency generation to an advantageous detection region [5, 6]. The conversion can occur in either a single pass [7], or an intra-cavity [8] configuration. The latter allows for higher powers of the pump beam which in turn yields higher efficiencies. By utilising quasi phase matched (QPM) crystals it is possible to select the desired detection window to a few nm which helps in the reduction of background noise and can be used further into the MIR, limited only by the transmission of the nonlinear crystals.

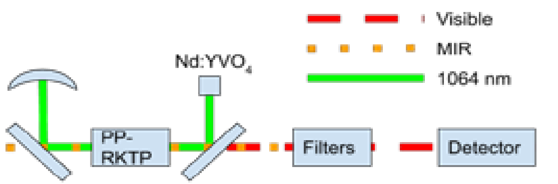

Fig. 1. A sketch of the detection cavity. The green line represent the oscillating 1,064 nm, the orange represents the MIR light and the red represents the up-converted visible light.

In this work a periodically poled rubidium doped $KTiOPO_4$ (PPRKTP) crystal was employed to convert pulses at 2.4 µm to 737 nm by intra-cavity mixing with 1,064 nm from a $Nd:YVO_4$ laser. The pulses at 737 nm was then detected using a conventional Si single photon avalanche photodiode (SPAD). A sketch of the lay out for this detection technique is shown in Fig. 1. The characteristics, such as dark count rate and temporal resolution, of this detector scheme is essentially limited only by the visible detector and the electrons since the SFG process is instantaneous. This allows for good range resolution when combined with time of flight technique for range determination.

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Progress in Ultrafast Optical Parametric Oscillators

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Harnessing the superior linear and nonlinear optical properties of new birefringent and quasi-phase-matched (QPM) crystals combined with advances in laser pump sources, together with the application of innovative design concepts, optical parametric oscillators (OPOs) have transformed solid-state laser technology in new directions and continue to break new barriers in all time-scales from the continuous-wave (cw) to few-cycle femtosecond pulses. The development of birefringent crystals such as BiB_3O_6 and QPM materials such as MgO:PPLN, combined with cw and ultrafast solid-state and fiber pump lasers near ~1 μm, have enabled advancement of OPO technology across vast spectral regions from ~250 nm in the UV up to ~4 μm in the mid-IR [1-3]. The recent advances in the growth and fabrication of new semiconductor nonlinear crystals, $CdSiP_2$ (CSP) and orientation-patterned GaP (OP-GaP), have now led to new breakthroughs in OPO technology, breaching the ~4 μm spectral barrier [4], and enabling wavelength generation across the entire 2-12 μm spectral range, remarkably even from a single device, using solid-state and fiber lasers near ~1 μm as the pump source.

In the ultrafast time-scale, operation of femtosecond OPOs into deep-IR at wavelengths as long as ~8 μm has been realized by exploiting birefringent CSP as the nonlinear material with external cascaded pumping using a commercial near-IR femtosecond OPO as the intermediate stage [5]. More recently, operation of ultrafast femtosecond OPOs has been achieved at wavelength beyond 8 μm in the deep-IR by direct pumping with the KLM Ti:sapphire laser, and without the need for intermediate cascaded step [6]. By exploiting type-I ($e \rightarrow oo$) critical phase-matching in CSP, the femtosecond OPO can provide continuous tuning across 7306–8329 nm (1201–1369 cm^{-1}) in the deep-IR. The oscillator delivers up to 18 mW of idler average power at 7306 nm and >7 mW beyond 8000 nm at 80.5 MHz pulse repetition rate, with the spectra exhibiting bandwidths of >150 nm across the tuning range. Moreover, the signal is tunable across 1128–1150 nm in the near-IR, providing up to 35 mW of average power in ~266 fs pulses at 1150 nm. Both beams exhibit single-peak Gaussian distribution in TEM_{00} spatial profile. With an equivalent spectral brightness of ~5.6 $\times 10^{20}$ photons s^{-1} mm^{-2} sr^{-1} 0.1% BW^{-1}, this OPO represents a viable alternative to synchrotron and supercontinuum sources for deep-IR applications in spectroscopy, metrology and medical diagnostics.

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Holographic waveguides recorded on photopolymer materials

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In this work we present a study of Holographic waveguides recorded in photopolymers [1, 2]. The holographic waveguides presented in this work are created by recording two holograms [3] in a glass substrate; the first hologram acting as an in-coupler element, and the second hologram acting as an out-coupler element. Then light is guided through the glass substrate by total internal reflection. This particular device can serve as a see-through display, which has numerous applications in incoming technologies closely related to augmented reality. The role that augmented reality is expected to play in our Society in the near future is out of doubt. Therefore there is a need to invest time and money in the research of new technologies with the aim of improving the visualization capacities of augmented reality devices. The optimization of the device proposed was basically centered on the photopolymer composition [4]. In this way some features such as low shrinkage, optimum refractive index modulation and recording sensitivity, thickness, etc. were controlled in order to fabricate the holographic waveguides.

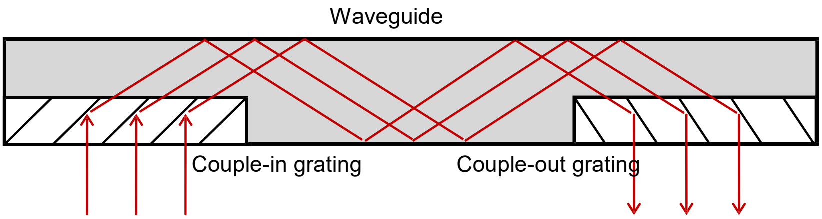

Fig. 1. Holographic Waveguide with two coupling gratings

In Figure 1 a scheme of the device and how it works is presented. In Figure 2 a photograph of the actual device is shown. From figure 2 it can be seen that the beam is guided through the device by the accomplishing of total internal reflection in the glass substrate.

Fig. 2. Holographic Waveguide

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Photonic Crystal supported surface electromagnetic waves and their use for generation of long propagating surface plasmon - polaritons and ultrasensitive label-free biosensing

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We report our recent results in the field of Photonic Crystal (PC) - supported surface electromagnetic (SEM) waves and their applications. They include the generation of ultralong propagating plasmons on thin Pd, Co, Au (in violet and UV spectral ranges) and Ag layers, see e.g. [1-3]. In particular, for *ferromagnetic* cobalt layers, we realized unprecedently narrow (equal to 0.02^0 thus corresponding to the surface plasmon propagation length exceeding 0.1 mm) for the field magnetoplasmonic resonance (Transversal Magneto-Optical Kerr Effect) with 11% magnitude [1]. Note, that for all these cases without a specially designed PC, this would be simply meaningless to speak about surface plasmon - polaritons, because the propagation length is just of the order of the wavelength.

For biosensing, we used "bare" (no metal coating) PC – external medium (water) interface, specially treated to chemisorb protein layers, for the study of kinetics of the interprotein interactions. Besides quite large sensitivity, 0.2 pg/mm^2, this approach has additional advantages due to the possibility to excite simultaneously *s*- and *p*-polarized SEM having very different penetration depths into an external medium. This enables to segregate surface and volume effects, thus drastically increasing both the sensitivity and reliability of the data obtained. Another advantage of our approach is the appearing possibility also to study interactions involving rather thick (of the order of one - two microns) objects such as bacteria, viruses, and certain cell organells – option unattainable for usual surface plasmon resonance-based detectors due to the short penetration depth of such plasmon - polaritons.

We have developed a chitosan-based protocol of PC chip functionalization for bacterial attachment and performed experiments on antibody binding to living *E. coli* bacteria measured in real time by the PC SEW-based biosensor. Data analysis reveals specific binding and gives the value of the dissociation constant for monoclonal antibodies IgG2b against bacterial lypo-polysaccharides equal to $K_D = 6.2 \pm 3.4$ nM [4]. *To our knowledge, this is the first demonstration of antibody binding kinetics to living bacteria by an optical biosensor*. These results give important corrections to the numbers obtained earlier in the studies made with isolated bacterial membranes, what is very important e.g. for the assessment of drag efficiency. They also pave the way for further sensor and other applications of Photonic Crystal - supported surface waves, and the corresponding perspectives will be discussed.

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Hybrid plasmonics for optical interconnects and sensing

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This paper gives an overview of the recent progress in hybrid plasmonics and its applications to optical interconnects for inter- and intra-chip communication as well as for bio-sensing for lab-on-a-chip integrated systems.

1. Introduction

Silicon photonics is being driven by the microelectronics industry because of the performance improvements that are enabled by introducing on-chip and chip-to-chip optical communications into computer systems. It also offers a way to substantially reduce the costs of integrated optical devices by taking advantage of the well-established fabrication tools that have been developed over the last half-century for silicon electronics. Nevertheless silicon-based photonic components are still an order of magnitude larger than their electronic counterparts due to diffraction limit of light. An alternative solution could be based on plasmonic waveguides, where light is tightly confined at the metal-dielectric interface area beyond the diffraction limit. Unfortunately propagation losses in these structures decrease propagation length to only few µm. Recently a new promising solution has appeared: hybrid plasmonic structures with unique properties of subwavelength light confinement and decreased loss due to hybrid (metal/dielectric/silicon) configuration.

Hybrid plasmonics can also provide a technology solution for lab-on-a-chip applications with nano-scale waveguiding and subwavelength light confinement, where ultra-compact configurations of ring resonators and Mach Zehnder interferometers allow to reach very high sensitivities and low detection limits.

2. Fabricated structures

A number of different passive components based on hybrid plasmonic waveguides have been simulated and fabricated including waveguide couplers and splitters [1], disk resonators [2], polarization beam splitters [3] etc. Active devices, switches and modulators based on MZ and ring/disk configurations have been also proposed [4,5]. Similar structures have been also realized as sensitive biosensors [6,7].

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Near field interference of ordered micro-optical elements and their far field intensity patterns

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Modern micro-optical technology is driven by extreme demands on optical functionality. With classical diffractive optics it gets more and more difficult to fulfill such demands of for instance creating point clouds of more than 40000 high contrast features with field angles of 160 deg. For such cases the design of two-dimensional diffractive optical elements needs high simulation power. This is mainly driven by the fact that all efficiency simulations have to be run with rigorous tools. The majority of designs today are done for plane wave illumination. If this constrain is lifted new approaches based on interference effects and interaction of a curved surface with a regularly ordered optical element might be used to create intensity patterns that achieve high performance for dot generation [1]. Such elements base their characteristics on diffraction and refraction and can be seen as thick diffractive optical elements with continuous surface profile. Usually they measure several 10 micron in widths and have a similar height. The strong deviation of rays together with large phase shifts in such structures leads to amplitude modulation although the structure itself has no absorption. Therefore in thick diffractive optical elements it is important to use advanced models for simulation that include both phase profiles and amplitude modulations.
In our contribution we study optical effects that can be expected when a thick diffractive optical element is illuminated under different beam conditions. We discuss different cases theoretically and give conditions for which interference effects leads to strong contrast variations in the far field. To study the optical field in amplitude and phase after the structure, we designed an instrument that allows placing a point source at a precise position in space and even in close vicinity to the structure. We will present details of the instrument and show examples of measurements together with simulations that support our concept.

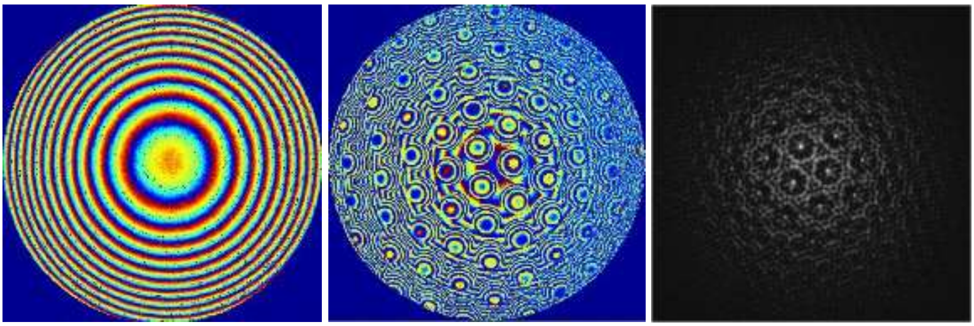

Fig. Left: Monomode Gaussian beam phase profile. Middle: Phase after the microlens array. The modulation of the phase by the microlens is visible. Right: Far field pattern at a defined position between then Gaussian beam waist and the microlens array.

STUDENT SESSION

Contrast of Diffraction Pattern from Sinusoidal phase gratings under Gaussian beam illumination

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Arbitrary light pattern generation using optical elements has various applications in imaging, lithography or microscopy. Generating a large numbers of almost equal intensity points with a wide field of view and high contrast in the far field is challenging. To do so, we investigate the point patterns generation using sinusoidal phase gratings under a diverging Gaussian beam illumination. The configuration is shown in Fig. 1. The Gaussian beam is a single mode TEM wave. We are particular interested in cases of different grating height *h* over period *P* ratios with the aim do study the influence of thick optical elements on dot generation. In our study we set the period at $P = 50$ *um* and the source wavelength is 650 *nm*. *D* is the distance between the source and the phase grating.

Generation of high contrast patterns in far-field can be achieved for particular values of the distance *D* as a result of interference effects of the curved wavefront and the grating. We are most interested in the contrast variation which we define as the standard deviation over mean value. In the case of thick microoptics one needs to use a rigorous simulation (Lumerical software package, FDTD method) for modelling the field propagation inside phase grating. As an example simulation the contrast variation around $D = 3.8$ *mm* for $h = 12$ *um* is shown in Fig. 2. There is a peak in the contrast curve, which is almost symmetric. We compare the simulation results with experiments for different *h* thicknesses from low to high.

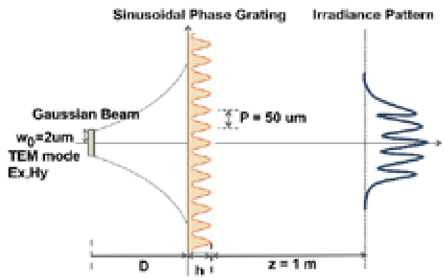

Fig. 1. Far field light pattern generation for sinusoidal phase grating under Gaussian beam illumination.

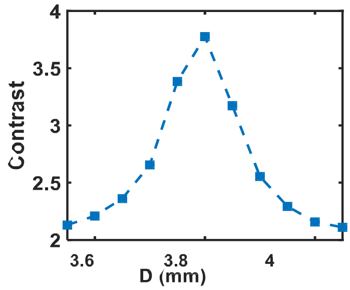

Fig. 2. Contrast versus *D* using rigorous FDTD method.

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Wave retarders and waveguide couplers made of anisotropic metamaterials

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Metamaterial structures typically comprise subwavelength-period arrays of specially designed nanoscatterers. Single metamolecular layers of these materials, called metasurfaces, have recently been under intense study for their extraordinary capabilities, including beam manipulation and creation of ultrathin optical components. Highly anisotropic metasurfaces have also been used for optical polarization control. As the polarization of light is easy to modulate, polarization-sensitive metasurfaces can be a useful building block in tomorrow's information-optical devices.

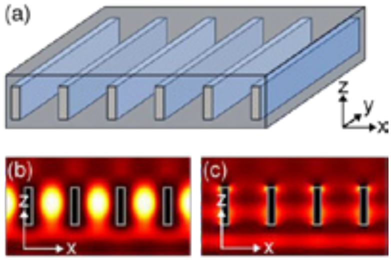

Fig. 1. Metamaterial wave plate. (a) Structure. (b) Intensity of a y-polarized normally incident plane wave. (c) Intensity of an x-polarized wave.

We introduce a metasurface wave plate that is capable of broadband operation with low losses [1]. The wave plate is composed of a one-dimensional array of thin metal stripes inside glass, as shown in Fig. 1a. It transmits both incident polarizations effectively (see Fig. 1b for the y- polarization and 1c for the x-polarization) and provides a prescribed phase retardation by the strong birefringence of the structure. We fabricate a quarter-wave plate based on this principle, and experimentally verify its properties. Due to the simplicity of the design, the wave plate can be fabricated on large substrates. In addition, they can be tuned to work in different wavelength regions.

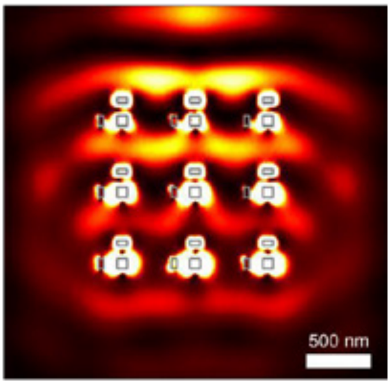

Fig. 2. Intensity distribution inside a slab waveguide with a nanotrimer-based waveguide coupler (grey rectangles represent silver nanobricks). The coupled light propagates upwards. The incident wave propagates normally to the array.

We also design a polarization-sensitive waveguide coupler with a small footprint (1.5 μm square). The coupler is composed of an array of *trimers*, groups of three silver nanobricks inside a TiO_2-glass-Ag slab waveguide. The trimers are tuned to efficiently scatter a normally incident wave into the waveguide (see the intensity distribution in Fig. 2). Furthermore, the propagation direction of the excited waveguide mode is decided by the polarization of the incident beam: x-polarized light is sent into the y-direction, and y-polarized light into the x-direction. Hence, any polarization modulation in the beam is transformed into *direction* modulation in the waveguide. The coupling efficiency of the coupler is 62 % (in the preferred direction) at the design wavelength of 780 nm, and the coupler has a bandwidth of about 110 nm. The coupler, if fabricated in a large array, can also be used for applications in light-harvesting devices.

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Diffusion model of light scattering in anisotropic media and extraction of fundamental properties

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Light diffusion in highly scattering materials is a topic of high interest, especially for the imaging of biological tissues which are anisotropic and highly scattering. However, description of a material requires values of fundamental properties as an input. In order to obtain these characteristics time resolved measurements need to be performed. In some cases, due to limitations of fabrication or structure it can be challenging. We present analytical solution of diffusion model and set of experiments that allow the determination of macroscopic properties, such as scattering and absorption coefficients, which are generally anisotropic. Also, we present the transport mean free path value that signifies the critical thickness after which scattering photons will dominate and the distribution will be fully described by the diffusion equation. From obtained values one can predict the photon path distribution and its average, transmission and absorption inside a scattering anisotropic material.

Partially coherent fractional vortex beam

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We introduce a new kind of partially coherent vortex (PCV) beam with fractional topological charge named partially coherent fractional vortex (PCFV) beam, which exhibits unique propagation properties. The cross-spectral density (CSD) of a PCV beam in the source plane is expressed as [1]

$$W(\boldsymbol{r}_1,\boldsymbol{r}_2)=\left(\frac{2r_1r_2}{w_0}\right)^l\exp\left(-\frac{r_1^2+r_2^2}{w_0^2}\right)\exp[-il(\theta_1-\theta_2)]\exp\left[-\frac{(\boldsymbol{r}_1-\boldsymbol{r}_2)^2}{\sigma_0^2}\right], \tag{1}$$

where $\boldsymbol{r}_k (k=1,2)$ and θ_k denote transverse position vectors and angle coordinates, respectively. l denotes the topological charge, which can be an arbitrary value, both integral and fractional. w_0 and σ_0 are the beam width and spatial coherence width, respectively. By choosing a fractional value of l, Eq. (1) represents the CSD function of a PCFV beam. In the focal plane, the CSD function of a PCFV beam can be written as

$$W(\boldsymbol{\rho}_1,\boldsymbol{\rho}_2)=\iint W(\boldsymbol{r}_1,\boldsymbol{r}_2)\exp[-i2\pi(\boldsymbol{r}_1\cdot\boldsymbol{\rho}_1-\boldsymbol{r}_2\cdot\boldsymbol{\rho}_2)]\mathrm{d}\boldsymbol{r}_1\mathrm{d}\boldsymbol{r}_2, \tag{2}$$

where $\boldsymbol{\rho}_k$ denotes the position vector in the focal plane. Based on Eq. (2), we calculate numerically the propagation properties (e.g., intensity and CSD) of a focused PCFV beam.
The normalized intensity and modulus of CSD distributions of a PCF beam with different l focused by a thin lens at focal plane for different values of σ_0 in Fig. 1.

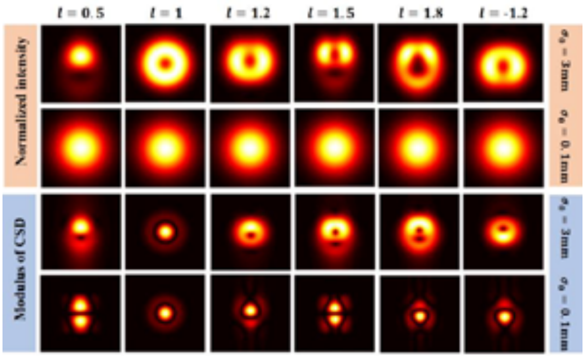

Fig. 1. Normalized intensity and modulus of CSD of a PCV beam with different l focused by a lens at focal plane for different values of σ_0.

For normalized intensity distribution, one finds that when σ_0 is large ($\sigma_0=$ 3mm), the topological charge l plays a decisive role in determining the focused intensity, namely, as l varies, the focused intensity profile of the PCV beam varies and displays unique distribution. While when σ_0 is small ($\sigma_0=0.1$mm), the difference between the focused intensity distributions of the PCV beams with different l disappears, and finally all intensity profiles become Gaussian profiles. For modulus of CSD distribution, it is interesting to find that whether high spatial coherence width or low spatial coherence width, the PCV beams with different l have their own unique distribution. Moreover, with the decrease of σ_0, the distribution of modulus of CSD becomes more symmetric and more exquisite. In particular, the distribution of modulus of CSD of the focused PCFV beam with half-integral topological charge (e.g. $l=0.5$ and 1.5) evolves from bilateral symmetry to rectangular symmetry.

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All-dielectric optical nanoantenna for dynamic beam steering

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Recent progress in the deployment of all-dielectric metasurfaces promises vast possibilities for the light control and potentially can replace the conventional refractive optics with more advanced and compact devices [1,2]. Significant interest is devoted to the active optical metasurfaces and nanoantennas that are able to control light in real time [3]. However, the remaining issues of the limited extent of the tunability in both amplitude and phase so far prevented the development of a practical adaptive plasmonic metasurface-based optics [4-6]. To tackle some of these challenges active low-lossy metasurfaces can be implemented for the next-generation of nano-optical devices.

We propose high refractive index all-dielectric metadevice that delivers tunable beam steering in transmission by applied external magnetic in the real time. Metadevice consists of ferrimagnetic low-loss (bismuth-yttrium iron garnets) split-ring nanoantennas array located on the gadolinium gallium garnet substrate with magnetic beam steering between forward and backward magnetic saturation in the out of plane of metasurfcae in the visible range. As a result, the beam propagation direction spans tens of degrees, controlled by the strength of the applied magnetic field in real time.

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FRIDAY, JULY 5

Metamaterials, Anapoles and Flying Donuts

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Metamaterials have been the platform for developing a new chapter in electrodynamics devoted to toroidal and anapole modes of excitation and the generation of electromagnetic flying donuts. Electromagnetic toroidal dipoles can be represented as currents flowing on the surfaces of tori. They provide physically significant contributions to the basic characteristics of matter including absorption, dispersion, and chirality. They give rise to dynamic anapoles, illusive non-radiating charge-current configurations. Toroidal excitations also exist in free space as spatially and temporally localized electromagnetic pulses, a topologically complex formation of vortices, propagating at the speed of light and interacting with matter in a way different from conventional electromagnetic transvers pulses. We discuss these recent findings and the role of localized and propagating electromagnetic toroidal excitations in light-matter interactions, spectroscopy and telecommunications.

Computational imaging with single-pixel detection: application to wavefront sensing and imaging through turbid media

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Computational imaging based on structured light permits to use light sensors without pixelated structure. The method is based on sampling the scene with a set of microstructured light patterns while a simple bucket detector, for instance a photodiode, records the light intensity transmitted, reflected or diffused by the object [1,2]. Images are then computed numerically from the photocurrent signal by using different mathematical algorithms. A common approach is to use light patterns codifying functions of a basis, such as Hadamard or Fourier components [2]. Images are retrieved by a simple basis transformation. The technique is also well adapted to apply compressive sensing algorithms by using different basis of functions to sample the object and to reconstruct the image [3].

The simplicity of the sensing device allows working efficiently in low light level conditions [4]. It also makes easier to record the spatial distribution of multiple optical properties of the light, such as the polarization state or the spectral content [5]. Single-pixel detectors permit to use a broader spectral range compared to conventional cameras, extending imaging techniques to exotic spectral regions [6]. Additionally, single pixel cameras have proved to be tolerant to light scattering under certain circumstances [7].

In this contribution, firstly we review computational imaging techniques based on structured light and single-pixel detection. We focus on optical systems using Walsh-Hadamard patterns as sampling functions. Second, we describe several applications of this technique on multidimensional imaging. In particular, we describe an optical system providing phase imaging by spatial wavefront sampling [8]. Finally, we show the potential of single-pixel imaging techniques to obtain images through turbid media and recent advances using Fourier filtering methods [9].

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Magnetic, chemical and electrical steering of optical nanoantennas

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A major challenge facing nanophotonics is the poor dynamic tunability. A functional adaptive nanophotonic element would feature the real-time large tunability of transmission and/or reflection of light's intensity and/or polarization, or the light's propagation direction over a broad range of wavelengths, and would be robust and easy to integrate. Several approaches have been explored so far including mechanical deformation [1], thermal [2] or refractive index [3] effects, and all-optical switching [4]. Building on our previous advances in nanofabrication [5] and the combination of the plasmonic and ferromagnetic materials (magnetoplasmonics) [6], we devise an ultra-thin chiroptical surface, built on 2D nanoantennas, where the chiral light transmission is controlled by the externally applied magnetic field with tunability exceeding 100%. Further, combining plasmon and molecular resonances [7], we use a practical combination of the large array of magnetoplasmonic antennas and the thin layers of molecular photoswitches to explore the plasmon-molecular strong coupling and the associated polaritonic chemistry of phototransformations. We use strongly-enhanced magneto-optics for sensing the sub-monolayer amounts of single-molecule-magnets with light [8]. Finally, in our latest work we visualize with atomic resolution the electrically-controlled reversible room-temperature melting of the atomically thin outer layers of the optical antennas [9].

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Integrated nanophotonics for information technologies and sensors: status and some options for the future

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Moore's famed law for microelectronics, more based on economics than technology predictions, can also be formulated for integrated photonics, showing a development even eclipsing that of electronics in size scaling. However, these technologies are complementary. The decades long development in shrinking footprint and improved performance of photonics integrated circuits has, however, seemingly slowed down in recent years, posing problems in e.g. interconnects in data centers with their ever increasing power requirements. Smaller footprint, lower power, more versatile photonics devices are desired.

Several routes are available for such nanophotonics: negative epsilon (meta) materials, high refractive index materials, quantum dots based structures, to name some. Each have their advantages and limitations regarding ubiquitous applications, and there has so far not emerged something corresponding to the role of silicon in electronics.

Modelling of photonics materials on atomic and molecular scales is probably mandatory to find out basic limitations and give some ideas for routes to novel materials.

The fact that the CMOS performance approaches thermodynamic limit opens for interdisciplinary research on alternate electronics, monolithically integrated with photonics, with ramifications on applications, system architectures and interface photonics/electronics. Emerging or novel materials play a pivotal role here. Current status as well as prospects are discussed in this presentation.

Ghost imaging in the spectral-domain and its application to broadband spectroscopy and optic al coherence tomography

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Ghost imaging measures the correlation function between the intensity emitted by a light source and the total (integrated) intensity transmitted (or reflected) by an object, such that the image can be reconstructed without the object to be actually seen. The essential nature of ghost imaging lies in the mutual correlation of the two non-interacting beams, and the image is obtained by summing over the different probing patterns weighted by the integrated signal from the detector [1]. Here, we demonstrate broadband ghost imaging in the spectral domain using a supercontinuum source [2,3]. We apply the technique to broadband spectroscopic detection of gases [2] as well to Fourier-domain optical coherence tomography for imaging of real physical objects [3]. In both cases, the spectral ghost imaging approach is in excellent agreement with direct measurements. The advantage of the correlation approach is that it detects the total integrated signal after the object and is thus very sensitive even in low light conditions or in spectral regions where no fast detector exists. It is also inherently insensitive to any perturbation occurring between the object and the detector.

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Motion estimation and quality enhancement for a single image in dynamic single-pixel imaging

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In a conventional camera, a pixelated sensor array is usually utilized to capture a two-dimensional image of the target object. However, single-pixel imaging (SPI) only requires a sensor with one single pixel for recording a photograph with two-dimensional spatial resolution. The object is sequentially illuminated with varying patterns and the total light intensity of the entire object scene is recorded as a single-pixel value by the detector at each time. Finally, the object image is computationally reconstructed from both the recorded single-pixel intensity sequence and the illumination patterns. SPI exhibits substantial advantages in some invisible wavebands where conventional pixelated sensor arrays are expensive or even not available [4]. In addition, SPI can realize indirect-line-of-sight imaging and imaging under weak light conditions.

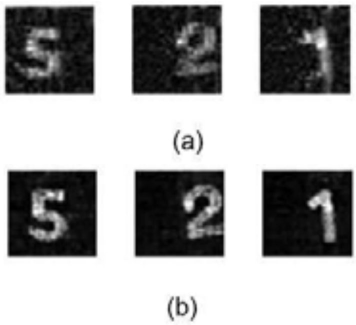

Fig. 1. Reconstructed images of printed digits on a fast-rotating disk with (a) conventional algorithm; (b) proposed algorithm.

In SPI, a large number of illuminations are usually required to capture one single image. Consequently, SPI may only achieve a very low frame rate for a fast-moving object and the reconstructed images are contaminated with blur and noise. In previous works, some attempts are made to perform motion estimation between neighboring frames in a SPI video to enhance the image quality. However, the motion estimation and quality enhancement from one single image frame in dynamic SPI was seldom investigated. In our recent work [1], it is assumed that some prior knowledge about the type of motion the object undergoes is known. A motion model of the target object is constructed and the motion parameters (e.g. shifting speed, rotating speed, rotation center) can be optimized within a search space. Then the object image is reconstructed from the single-pixel intensities using the transformed illumination patterns with optimized parameters instead of the original patterns.

Our proposed scheme is different from common motion deblur techniques for photographs since the motion blur mechanism in SPI is significantly different from a conventional camera. Experimental results demonstrate that the reconstructed images with our proposed scheme in dynamic SPI have much better quality. In Fig. 1, some examples of reconstructed images with conventional algorithms and with our proposed algorithms are demonstrated.

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Information rates in EDFA and Raman amplified optical communication systems using nonlinearity compensation

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Optical networks form an integral part of the world-wide communication infrastructure and nowadays over 95% of data traffic is carried over fibres. Erbium-doped fibre amplifiers (EDFAs) and Raman amplifiers have made it possible to extend the usable fibre bandwidth to increase the achievable capacity of optical communications in past decades to meet the ever-growing information rate demands. However, these amplification technologies are now viewed as limiting the accessible optical spectrum to ~5 THz and ~10-15 THz, respectively. Currently, the presence of Kerr effects in fibre channels has been largely regarded as the major bottleneck for enhancing achievable information rates of optical communications. Signal performance degradations due to fibre nonlinearities are more severe in the systems utilising larger transmission bandwidths, closer channel spacing and higher-order modulation formats. In this work, we will investigate the behaviour and compensation of Kerr effects to analyse the performance of optical fibre communication systems using EDFAs and Raman amplifiers. Information rates of such ultra-wideband optical transmission systems will be discussed considering the nonlinearity compensation and transceiver limitations.